GENERAL ATOMIC

DIVISION OF **GENERAL DYNAMICS**

GA-6509

ANNUAL STATUS REPORT
ON THE THEORY OF HYPERVELOCITY IMPACT

Advanced Research Projects Agency
ARPA Order No. 71-62
Monitored by
Ballistic Research Laboratories
Army Contract DA-04-495-AMC-116(X)

June 28, 1965

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ANNUAL STATUS REPORT ON THE THEORY OF HYPERVELOCITY IMPACT

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The revised Common and FORTRAN listings for the OIL code described herein are as they existed on July 1, 1965. The OIL code has been in continuous development for 3 years and in its presented form has been applied successfully by General Atomic to the kind of problems discussed later in this report. However, the development and improvement of the code are being continued, so that duplication of results (or even close agreement) between problems run with the code as published and the code as it existed either before or after this time is not necessarily to be expected.

ABSTRACT

The three principal areas of activity,

1. Numerical solutions of problems in impact,
2. Code development for solving impact problems, and
3. Analytical work on the theory of the impact process,

are reviewed, utilizing wherever possible cited papers which have been published during this past year as part of the project work. The investigations covered in these papers are described only briefly in the present status report, familiarity with or availability of the original documents being assumed.

The major part of the present discussion is devoted to a status report of unfinished work on the problem of computing strength-dependent and viscous impact flows. A computer program is described for generalizing Eulerian hydrodynamic codes to include these effects and sample calculations are given.

CONTENTS

I. SUMMARY OF WORK AND INTRODUCTION TO PRESENT REPORT

The major areas of work in the present contract period are summarized below to give the current status of each area and to cite where appropriate project documents that have been written.

1.1. STUDIES OF IMPACT HYDRODYNAMICS

Work in this area is the subject of the paper, "On the Theory of Hypervelocity Impact," by J. M. Walsh and W. E. Johnson, which appears in the Proceedings of the Seventh Hypervelocity Impact Symposium, Volume II, pages 1—76, February 1965. This paper is partially an exposition of the thick-target hydrodynamics studies given in our preceding annual report; it also contains a Part II which is devoted to a selection of impacts with thin-plate targets. The cited report is widely circulated, and many of the results will also be the subject of discussion in a joint report under preparation by General Atomic and the Ballistic Research Laboratories (see Section 1.5). Accordingly, it does not seem desirable to detail the work on impact hydrodynamics as part of the present report.

1.2. CODE DEVELOPMENT WORK IN HYDRODYNAMICS

This effort has consisted primarily of the development of improved computer programs for the solution of hydrodynamic flows which are functions of two space variables and time. The principal result is the continuous Eulerian code, OIL, developed over the preceding and present contract periods and documented in the report, "OIL— A Continuous Two-dimensional Eulerian Hydrodynamic Code," by W. E. Johnson, published as General Atomic Informal Report GAMD-5580 (Rev.), January 1965.

Additional improvements that have been made in the OIL code subsequent to the time the above report was issued are contained in the present report as part of Section III. The more significant changes are an improved treatment of free surfaces, and a capability for solving time-dependent x-y flows in addition to time-dependent axisymmetric flows.

1.3. CODE DEVELOPMENT WORK IN VISCOUS AND STRENGTH-DEPENDENT FLOWS

For most of the past year, the principal objective of the effort has been the development of a suitable code for the solution of two-dimensional viscous flows and two-dimensional flows in which strength-dependent deformation is important. Since Eulerian hydrodynamics codes have been more successful t.an Lagrangian codes in handling the large material distortions characteristic of impact, it was decided to retain the Eulerian code, OIL, and to generalize it to treat the tensor forces that arise from viscosity and strength.

In adding viscous and strength options to the OIL code, the approach used has been to leave the hydrodynamic capabilities of the code essentially unmodified and to add a separate phase in which viscous and strength forces are then taken into account to alter the velocities and specific internal energies. In other words, the average hydrostatic stress and compressions are accounted for in the hydrodynamics as usual; the task of the new phase (called PH3) is to take account of the stress deviator tensor which arises from the strain deviator tensor. For simplicity and to circumvent any need for storing components of the stress or strain deviators, the constitutive equations have so far been picked to be of special types. Specifically, the strength is represented by a rigid-plastic set of constitutive equations and the viscosity has so far been taken to be Newtonian. Generalization of these classical models will presumably be straightforward, although the retention of an elastic phase will require storing components of the stress tensor

The viscous and strength generalizations of the OIL code are given in considerable detail in the present report. The basic equations are the subject of discussion as Section II and the code is described in Section III and is reproduced as Section IV. The viscous and strength program, PH3, is of such a nature that it could be added to most multidimensional PIC-type or Eulerian hydrodynamic codes without disturbing the hydrodynamics capability, as was the case with OIL. It is then possible to add these effects in a hydrodynamics problem or to omit them by merely by-passing PH3 each time step. One rewarding feature of including viscosity, however, has been a significantly improved and smoother hydrodynamics. It seems probable that some viscosity will prove desirable in most purely hydrodynamic problems in order to smooth spurious oscillations. Examples of computations with and without viscosity are reproduced in Section III.

While the viscous option is apparently giving a smooth solution in a very satisfactory manner, there is a remaining difficulty in the form of small oscillations in the strength version of the code. These oscillations (which prevent the flow from being completely arrested) can be ignored, although additional code development work to remove them will probably be carried out prior to any extensive production applications.

It is expected that the completed code will provide a general capability for solving strength and viscous deformation problems and that its most important application may be to those flows where material distortions are sufficiently great that Lagrangian schemes become unmanageable. Our primary attention will be to cratering problems, such as those occurring in impact, and some work of this type is presented in Section III.

The computing time for the strength or viscous options in OIL is roughly equal to that for the purely hydrodynamic part of the calculation. Finally, FORTRAN listings for the hydrodynamic sections of OIL are also reproduced in Section IV, as a convenient way to document minor modifications which are described in the text.

1.4. ANALYTICAL WORK ON IMPACT AND RELATED PROBLEMS

Several analytical studies pertinent to various aspects of impact mechanics have been reported during the past contract period. These include:

"Late-stage Equivalence and Similarity Theory for One-dimensional Impacts," by J. K. Dienes. This paper is a discussion of simple ideal-gas impacts and exposes most of the physical principles underlying the more complex numerical work on axisymmetric solid-solid impact. Since the paper is presented in the Proceedings of the Seventh Hypervelocity Impact Symposium, Volume II, pages 187—220, February 1965, additional discussion here does not appear necessary.

"Approximate Treatment of Plane Shock Attenuation in a Solid," by J. M. Walsh, General Atomic Informal Report GAMD-5214, May 1964. This is an approximate theory of slab impacts of solids and has been previously distributed.

"Hydrodynamic Flow Equations with a Plasticity Resistance Law," by J. K. Dienes, General Atomic Informal Report GAMD-5910, December 1964. This is a summary of the relevant theoretical mechanics underlying the viscous and strength formulations and is also largely reproduced as Section II of the present report.

"A General Form for Matrix Functions of Nonsingular Second-degree Matrices," by T. Teichmann, General Atomic Report GA-6063, March 1965. This report does not apply directly to impact mechanics, but it does give a theorem in matrix algebra which was proved as an incidental result of work by Teichmann on a similarity theory of impact.

"Impact Crater Size and Target Strength," by F. E. Allison, J. K. Dienes, and J. M. Walsh, General Atomic Informal Report GAMD-6453, June 1965. Suitable simplifying assumptions are used to show that the dependencies of crater volume on impact velocity and target yield strength are closely related. For example, a proportionality of volume to impact

velocity leads to the result that crater volume varies inversely as the first power of the yield strength. The report has been distributed and additional work is planned.

"Remarks on Similarity Solutions for Hypervelocity Impact," T. Teichmann, General Atomic Informal Report GAMD-6501, July 1965. This is a general mathematical discussion of the similarity methods which have so far been used on the hypervelocity impact problem. The report will be distributed in the near future.

1.5. PREPARATION OF A COMPREHENSIVE EXPERIMENTAL-THEORETICAL REPORT ON THE DYNAMICS OF IMPACT

In conjunction with appropriate members of the Ballistic Research Laboratories and the Drexel Institute of Technology, it has been decided that a joint experimental-theoretical report on impact might provide a timely and integrated picture of this general field of activity. Much of the past work by General Atomic will be presented in this report, which is planned for completion in the summer of this year. Accordingly, the emphasis in the present report has been on those subjects which will not be extensively reviewed in this forthcoming discussion.

II. EQUATIONS FOR VISCOUS AND STRENGTH-DEPENDENT FLOWS

The flow equations for the motion of a fluid with a general resistance law can be written, in tensor notation,[1] as

$$\frac{D\rho}{Dt} + \rho\theta = 0 ,$$

$$\rho \frac{Du_i}{Dt} = S_{ij,j} ,$$

$$\rho \frac{D}{Dt}\left(I + \frac{1}{2} u_k u_k\right) = (S_{ij}u_i)_{,j} ,$$

where the summation convention is understood and S_{ij} denotes a general stress tensor, I is the internal energy per unit mass, ρ the density, and u_i the velocity vector, $\theta = u_{i,i}$ is the divergence of the velocity, and

$$\frac{D}{Dt} = \frac{\partial}{\partial u} + u_i \frac{\partial}{\partial x_i}$$

denotes the convective derivative. It is appropriate to express the stress tensor, S_{ij}, as the sum of a hydrodynamic part, $-p\delta_{ij}$, and a deviator part, σ_{ij}.

$$S_{ij} = -p\delta_{ij} + \sigma_{ij}$$

such that

$$\sigma_{ii} = 0 , \qquad p = -\frac{1}{3} S_{ii} .$$

The equations of motion can then be written as

$$\frac{D\rho}{Dt} + \rho\theta = 0 ,$$

[1] W. Prager, Introduction to Mechanics of Continua, Ginn and Company, 1961.

$$\rho \frac{Du_i}{Dt} = -p_{,i} + \sigma_{ij,j} ,$$

$$\rho \frac{D}{Dt}\left(I + \frac{1}{2} u_k u_k\right) + p\theta = (\sigma_{ij} u_i)_{,j} = \sigma_{ij} e_{ij} + \sigma_{ij,j} u_i ,$$

where

$$e_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$$

is the strain-rate tensor.

Now the average stress, p, is a known function of the density, ρ, and specific internal energy, I, through an equation of state, $p = f(\rho, I)$. In order to complete the description of the flow, it is necessary that the stress deviator tensor be related to the strain deviator tensor through a constitutive equation, which in the OIL code is taken to be of the general form

$$\sigma_{ij} = b\epsilon_{ij}, \qquad \epsilon_{ij} = e_{ij} - \delta_{ij}\,\theta/3 .$$

Three special cases are of particular interest. If b is constant, the constitutive equation describes purely viscous flows and b is twice the viscosity, μ, of the fluid. The second case,

$$b = (2K^2/E_2)^{1/2}, \qquad E_2 \equiv \epsilon_{ij}\,\epsilon_{ij} ,$$

describes a rigid-plastic material of the Prandtl-Reuss type for which the second stress invariant, $J_2 = \sigma_{ij}\,\sigma_{ij}$, can be shown to be constant and equal to $2K^2$, where K is the yield stress in pure shear. The third case defines equations of the Perzyna type in which strain-rate effects are accounted for by allowing b to have the general form $b = f(J_2)$, for which the function f has to be estimated in such a way that the solution to the equations of motion agrees with material-test observations. In the notation of Perzyna,[2]

[2] P. Perzyna, "The Study of the Dynamic Behavior of Rate-sensitive Plastic Materials," Division of Applied Mathematics, Brown University, Technical Report No. 77, May 1962.

$b = \sqrt{J_2}/\gamma\Phi(F)$, where $F = (\sqrt{J_2}/K) - 1$. In order to make use of the Perzyna equations in the current Eulerian code, OIL, the scalar b must be known as a function of the second strain invariant, E_2, which in turn can be obtained from the known velocity field. This is done by deriving from the constitutive equation the relation

$$J_2 = b^2(J_2)\, E_2 \; ,$$

which must be solved to find b as a function of E_2. Using the Perzyna notation, one finds

$$E_2 = \gamma^2 \, \Phi^2(F) \; .$$

The solution of this equation for J_2 in terms of E_2 is written, symbolically,

$$J_2 = K^2 \, \phi^2(E_2/\gamma^2) \; ,$$

and, in general, must be found by numerical methods. Then,

$$\sigma_{ij} = \frac{K\gamma}{\sqrt{E_2}} \, \phi(E_2/\gamma^2) \, \epsilon_{ij} \; ,$$

which is of the required form since the right-hand side can be obtained in terms of the velocity field and appropriate derivatives. From the point of view of the OIL code, the principal feature of the rigid-plastic model is that the constitutive equation does not depend on the total strain but only on the rate of strain, which can be determined by appropriate operations on the velocity field. The general elastic-plastic calculation, which is discussed in Ref. 3, would require that the strain itself be known and, therefore, would entail a significant increase in memory, in complexity of the code, and in computer time necessary to solve impact problems.

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[3] J. K. Dienes, "Hydrodynamic Flow Equations with a Plasticity Resistance Law," General Atomic Informal Report GAMD-5910, December 1964.

In cylindrical coordinates the strain-rate tensor is given by the matrix

$$
(e_{ij}) = \begin{pmatrix} \dfrac{\partial u}{\partial r} & 0 & \dfrac{1}{2}\left(\dfrac{\partial u}{\partial z} + \dfrac{\partial v}{\partial r}\right) \\ 0 & \dfrac{u}{r} & 0 \\ \dfrac{1}{2}\left(\dfrac{\partial u}{\partial z} + \dfrac{\partial v}{\partial r}\right) & 0 & \dfrac{\partial v}{\partial z} \end{pmatrix} ,
$$

where u denotes the radial velocity (u_1 in the generalized notation) and v denotes the axial velocity (u_3 in the generalized notation). The first strain-rate invariant, E_1, is also the divergence of the velocity, and is, in cylindrical coordinates,

$$
E_1 = \theta = e_{ii} = \frac{\partial u}{\partial r} + \frac{u}{r} + \frac{\partial v}{\partial z} .
$$

The second strain-rate invariant is

$$
E_2 = \left(e_{ij} - \frac{1}{3}\,\theta\,\delta_{ij}\right)\left(e_{ij} - \frac{1}{3}\,\theta\,\delta_{ij}\right) = e_{ij}\,e_{ij} - \theta^2/3 ,
$$

which, in cylindrical coordinates, becomes

$$
E_2 = \frac{2}{3}\left[\left(\frac{\partial u}{\partial r}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 + \left(\frac{u}{r}\right)^2\right] + \frac{1}{2}\left(\frac{\partial u}{\partial z}\right) + \left(\frac{\partial v}{\partial r}\right)^2 .
$$

The flow equations can be written in such a way that the local time derivatives appear on the left-hand side and the right-hand side is the sum of three terms. The first gives the effect of convection, the second the effect of hydrodynamic forces, and the third term gives the effect of the deviator stresses. The first two terms are accounted for in the original OIL code and are discussed separately.[4] The additional increments due to the deviator stress terms are accounted for in the strength code and

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[4] W. E. Johnson, "OIL, A Continuous Two-Dimensional Eulerian Hydrodynamic Code," General Atomic Informal Report GAMD-5580, October 15, 1964.

are the subject of this section. The full equations for the general case are:

$$\frac{\partial \rho}{\partial t} = -u_i \rho_{,i} - \rho\theta ,$$

$$\rho \frac{\partial u_i}{\partial t} = -\rho u_j u_{i,j} - P_{,i} + \sigma_{ij,j} ,$$

$$\rho \frac{\partial}{\partial t}\left(I + \frac{1}{2} u_k u_k\right) = -\rho u_j I_{,j} - p\theta + (\sigma_{ij} u_i)_{,j} .$$

Expressions for the co-variant derivatives in general coordinates are derived in tensor analysis. The appropriate expressions for cylindrical coordinates are given by Sokolnikoff.[5] Denoting by a δ the increments due to stress deviator terms, the above equations lead to the following expressions for the effect of material strength in cylindrical coordinates:

$$\rho \frac{\delta u}{\delta t} = \frac{1}{r} \sigma_{rr} + \frac{\partial}{\partial r} \sigma_{rr} + \frac{\partial}{\partial z} \sigma_{rz} - \frac{1}{r} \sigma_{\theta\theta} ,$$

$$\rho \frac{\delta v}{\partial t} = \frac{\partial}{\partial r} \sigma_{rz} + \frac{\partial}{\partial z} \sigma_{zz} + \frac{1}{r} \sigma_{rz} ,$$

$$\rho \frac{\delta\left(I + \frac{1}{2} u_k u_k\right)}{\delta t} = \frac{1}{r} \frac{\partial}{\partial r} \left[r(u\sigma_{rr} + v\sigma_{rz})\right] + \frac{\partial}{\partial z} (u\sigma_{rz} + v\sigma_{zz}) .$$

These expressions can be integrated over the finite volumes associated with each cell to obtain expressions appropriate for the effects of deviator stresses alone. As a result of this calculation for the element of volume in Fig. 1, one finds

$$\delta u = \frac{2\pi\delta t}{\Delta m} \left\{ r\sigma_{rr} \Big|_{r}^{r+\Delta r} \Delta z + \sigma_{rz} \Big|_{z}^{z+\Delta z} \left(r + \frac{\Delta r}{2}\right) \Delta r - \sigma_{\theta\theta} \Delta z \Delta r \right\} ,$$

---

[5] I. S. Sokolnikoff, Mathematical Theory of Elasticity McGraw-Hill Book Company, 1946.

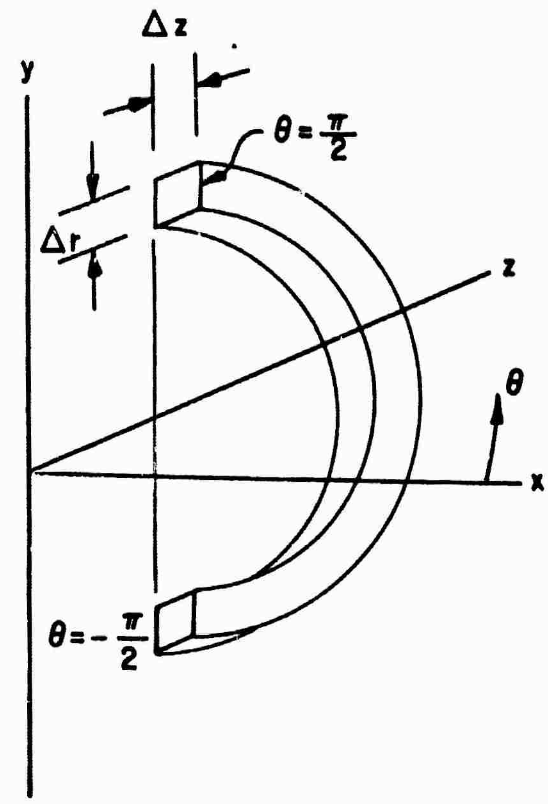

Fig. 1--The element of volume appropriate for deriving the flow equations in cylindrical coordinates; the contained mass is half the cell mass, Δm

$$\delta v = \frac{2\pi\delta t}{\Delta m}\left\{ r\sigma_{rz}\Big|_{r}^{r+\Delta r}\Delta z + \sigma_{zz}\Big|_{z}^{z+\Delta z}\left(r + \frac{\Delta r}{2}\right)\Delta r\right\},$$

$$\delta\left(I + \frac{1}{2}u_k u_k\right) = \frac{2\pi\delta t}{\Delta m}\left\{ r(\sigma_{rr}u_r + \sigma_{rz}u_z)\Big|_{r}^{r+\Delta r} + \left(r + \frac{\Delta r}{2}\right)(\sigma_{rz}u_r + \sigma_{zz}u_z)\Big|_{z}^{z+\Delta z}\right\}.$$

These are the expressions used in the viscous and strength options of OIL.

The stresses are evaluated at the cell boundaries in the code. The flux of each component of momentum and of energy across each cell boundary is added to one cell and subtracted from the other in such a way that the total energy and momentum are conserved in the finite difference approximation.

III. OIL WITH STRENGTH AND VISCOSITY

3.1. INTRODUCTION

In the hydrodynamic version[4] of OIL, the only stress acting is the scalar pressure, which is computed from a given function of density and specific internal energy. The incorporation of material strength and viscous forces into the code gives rise, however, to tensor forces which must be computed using the constitutive equations and then accounted for by using the appropriate momentum and energy equations discussed in the preceding section. These calculations have been programmed into a single (optional) phase in the code and are performed each time step. This phase of the combined code, called PH3, is currently located after PH1 (where the field terms in the hydrodynamic equations are computed) and prior to PH2 (where material transport is performed). Provisions have been made for by-passing PH3 to perform a purely hydrodynamic calculation and also for subcycling PH3 in order to split the time step for that phase only.

The additional coding required for the present options and anticipated coding for further modifications necessitated a decrease in the maximum allowable number of cells from 3,500 to 2,500.

Most of the present section is devoted to a description of the strength and viscosity programs. Some changes have been made to the basic OIL code, however, and these are also described. Among these are options for changing physical units and for treating flows in x-y space as well as the axisymmetric case. An improved treatment of free-surface motion is also incorporated.

3.2. DIFFERENCE EQUATIONS FOR PH3

In the following discussion, we have assumed that $\Delta x(i)$ for all i is a constant and $\Delta y(j)$ for all j is a constant. The space is axisymmetric and cylindrical coordinates are used, although Δx and Δy are used to designate cell dimensions in the R and z directions, respectively, as depicted in Fig. 2.

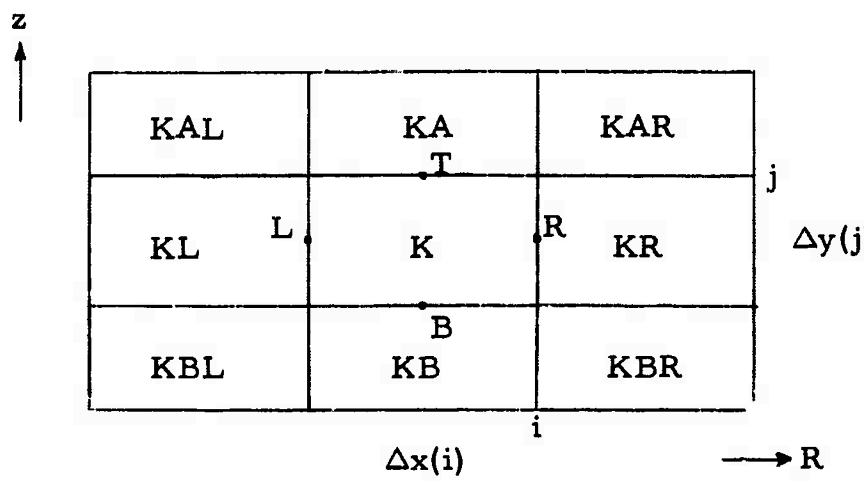

Fig. 2

To calculate the stresses at the cell boundaries, we compute the velocity gradients at points B, L, T, and R, as follows: The velocity gradients at points L and B have already been calculated from the previous row sweep and from the cell to left, and it suffices to indicate the procedure at R and T. Referring to the position R,

$$\frac{du}{dR} = \frac{u_{(KR)} - u_{(K)}}{\Delta x(i)} = \text{S1 (FORTRAN designation)},$$

$$\frac{dv}{dR} = \frac{v_{(KR)} - v_{(K)}}{\Delta x(i)} = \text{S2 (FORTRAN designation)},$$

$$\frac{du}{dz} = \frac{\dfrac{u_{(KA)} + u_{(KAR)}}{2.} - \dfrac{u_{(KB)} + u_{(KBR)}}{2.}}{2\Delta y(j)} = \text{S3 (FORTRAN designation)},$$

$$\frac{dv}{dz} = \frac{\dfrac{v_{(KA)} + v_{(KAR)}}{2.} - \dfrac{v_{(KB)} + v_{(KBR)}}{2.}}{2\Delta y(j)} = \text{S4 (FORTRAN designation)},$$

and

$$\frac{u}{R} = \frac{u_{(KA)} + u_{(K)}}{x(i) + x(i-1)} = \text{S10 (FORTRAN designation)}.$$

With these velocity gradients, we can calculate the stresses at the cell boundaries. The stresses are defined as

$$\sigma_{ij} = b\left(e_{ij} - \delta_{ij}\frac{e_{aa}}{3}\right) \equiv b\mathcal{E}_{ij} \ ,$$

$$\delta_{ij} = \text{Kronecker delta},$$

$$e_{aa} = \frac{dv}{dR} + \frac{dv}{dz} + \frac{u}{R} \ .$$

For a rigid-plastic material, the Prandtl-Reuss equations are given by

$$b = \sqrt{\frac{2eK^2}{\mathcal{E}_{ab}\,\mathcal{E}_{ab}}}$$

where K is the yield strength and

$$\mathcal{E}_{ab}\,\mathcal{E}_{ab} = \frac{2}{3}\left[\left(\frac{du}{dR}\right)^2 + \left(\frac{dv}{dz}\right)^2 + \left(\frac{u}{R}\right)^2\right] + \frac{1}{2}\left(\frac{du}{dz} + \frac{dv}{dR}\right)^2 \ .$$

Eight of the nine stresses acting on a cell in the axisymmetric case are:

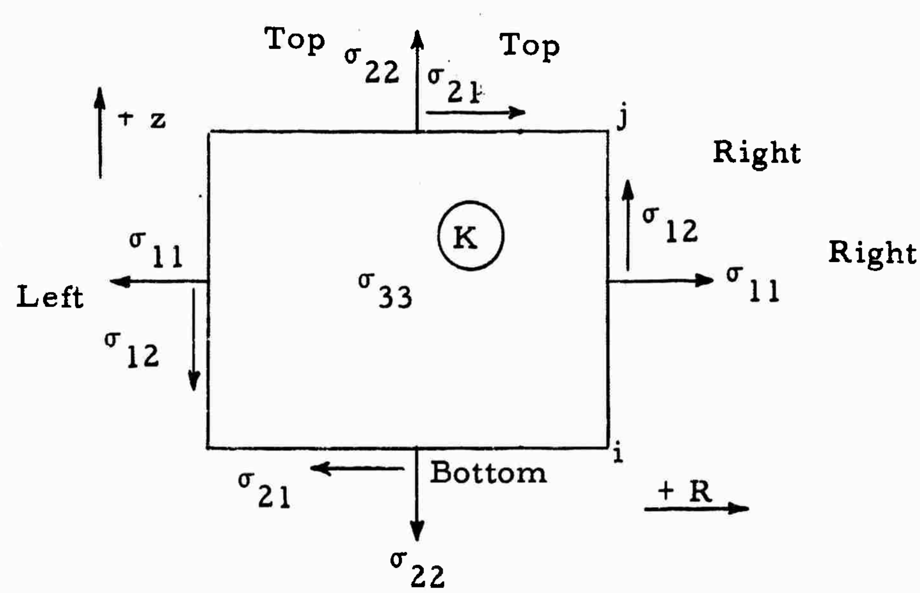

Fig. 3

Referring to Fig. 3, we define the hoop stress, which is normal to the plane of the paper, as shown here, and is positive in tension, as follows:

$$\sigma_{33} = b\varepsilon_{33} = \text{DDVK (FORTRAN designation)},$$

where

$$\varepsilon_{33} = e_{33} - \frac{1}{3} e_{aa} \; ,$$

$$e_{33} = \frac{2u_{(K)}}{x(i) + x(i-1)} \; ,$$

and

$$b = \sqrt{\frac{2K^2}{\Delta}} \; .$$

Here again, K is the yield strength and

$$\Delta = \frac{2}{3}\left[\left(\frac{u_{(KR)} - u_{(KL)}}{2\Delta y(j)}\right)^2 + \left(\frac{v_{(KA)} - v_{(KB)}}{2\Delta y(j)}\right)^2 + \left(\frac{2u_{(K)}}{x(i) + x(i-1)}\right)^2\right]$$
$$+ \frac{1}{2}\left(\frac{u_{(KA)} - u_{(KB)}}{2\Delta y(j)} + \frac{v_{(KR)} - v_{(KL)}}{2\Delta x(i)}\right)^2 \; .$$

The five stresses produce forces on cell K in the radial direction as follows:

The force at the <u>right side</u> of the cell is $F_{11}^{R} = \sigma_{11}^{R} \, \Delta y(j) 2\pi x(i)$;

at the <u>left</u> it is $F_{11}^{L} = -\sigma_{11}^{L} \, \Delta y(j) 2\pi x(i-1)$;

at the <u>top</u> it is $F_{21}^{T} = \sigma_{21}^{T} \, \pi(x(i)^2 - x(i-1)^2)$;

at the <u>bottom</u> it is $F_{21}^{B} = -\sigma_{21}^{B} \, \pi(x(i)^2 - x(i-1)^2)$;

and the hoop stress has a radial contribution given by

$$F_{33} = -\sigma_{33} \, 2\pi\Delta x(i)\Delta y(j) \; .$$

From the equation of motion then, the sum of these five forces results in the change Δu of cell K as follows:

$$\Delta u_{(K)} = \frac{2\pi\Delta t}{AMX(K)}\left[\sigma_{11}^{R}\,\Delta y(j)x(i) - \sigma_{11}^{L}\,\Delta y(j)x(i-1) + \frac{\sigma_{21}^{T}}{2}\left(x(i)^2 - x(i-1)^2\right) - \frac{\sigma_{21}^{B}}{2}\left(x(i)^2 - x(i-1)^2\right) - \sigma_{33}\Delta x(i)\Delta y(j)\right]$$

Only four stresses acting on cell K produce a change Δv in the axial direction:

The force at the top of the cell is $F_{22}^{T} = +\sigma_{22}^{T}\,\pi(x(i)^2 - x(i-1)^2)$;

at the bottom of the cell it is $F_{22}^{B} = -\sigma_{22}^{B}\,\pi(x(i)^2 - x(i-1)^2)$;

at the right it is $F_{12}^{R} = \sigma_{12}^{R}\,2\pi x(i)\Delta y(j)$;

at the left it is $F_{12}^{L} = -\sigma_{12}^{L}\,2\pi x(i-1)\Delta y(j)$.

These four forces then produce a change of Δv in cell K:

$$\Delta v_{(K)} = \frac{2\pi\Delta t}{AMX(K)}\left[\left(\frac{\sigma_{22}^{T} - \sigma_{22}^{B}}{2}\right)\left(x(i)^2 - x(i-1)^2\right) + \Delta y(j)\left(\sigma_{12}^{R}\,x(i) - \sigma_{12}^{L}\,x(i-1)\right)\right].$$

The change of total energy E of cell K that is due to the work done by these forces is

$$M\frac{dE}{dt} = \sum_{1}^{4} FV$$

over all four sides of cell K or, introducing the specific internal energy I,

$$M\frac{d}{dt}\left[I + \frac{1}{2}\left(u^2 + v^2\right)\right] = \sum_{1}^{4} FV \; .$$

Then, using the previous values for the interface forces and velocities, the internal energy I of cell K is

$$\Delta I_{(K)} = \frac{\Delta t}{AMX(K)} \left[\frac{u_{(KR)} + u_{(K)}}{2.} \{2\pi x(i)\Delta y(j)\sigma_{11}{}^{R}\} \right.$$

$$- \frac{u_{(K)} + u_{(KL)}}{2.} \{2\pi x(i-1)\Delta y(j)\sigma_{11}{}^{L}\}$$

$$+ \frac{u_{(K)} + u_{(KA)}}{2.} \{\sigma_{21}{}^{T} \pi(x(i)^2 - x(i-1)^2)\}$$

$$- \frac{u_{(K)} + u_{(KB)}}{2.} \{\sigma_{21}{}^{B} \pi(x(i)^2 - x(i-1)^2)\}$$

$$+ \frac{v_{(KR)} + v_{(K)}}{2.} \{\sigma_{12}{}^{R} \Delta y(j)x(i)2\pi\}$$

$$- \frac{v_{(K)} + v_{(KL)}}{2.} \{\sigma_{12}{}^{L} \Delta y(j)x(i-1)2\pi\}$$

$$+ \frac{v_{(K)} + v_{(KA)}}{2.} \{\sigma_{22}{}^{T} \pi(x(i)^2 - x(i-1)^2)\}$$

$$\left. - \frac{v_{(K)} + v_{(KB)}}{2.} \{\sigma_{22}{}^{B} \pi(x(i)^2 - x(i-1)^2)\} \right]$$

$$- \left[u_{(K)} \Delta u_{(K)} + v_{(K)} \Delta v_{(K)} + \frac{(\Delta u_{(K)})^2}{2.} + \frac{(\Delta v_{(K)})^2}{2.} \right] .$$

All the velocities are those from the PH1 hydrodynamics calculation. The T, R, B, and L refer respectively to the top, right, bottom, and left boundary of the cell in question.

3.3. LOGIC OF PH3

For either the strength or viscosity options, the forces are determined from velocity gradients, for which knowledge of velocities in neighboring cells to the particular one being treated is required. Furthermore, all of the velocities used in computing derivatives must correspond to the same time. These requirements necessitate retaining un-updated velocities for some cells as well as the updated values. These dual storage requirements are satisfied without additional working storage by equivalencing with working storage used in other parts of OIL; also, the sweep through the grid is done by rows rather than columns as elsewhere in OIL in order to take advantage of the fewer number of cells per row (52 maximum instead of 100 in a column). Hence, less storage is needed to retain old and new velocities for the two rows required.

The task of PH3, in general terms, is to compute the stresses from the old velocities and to use the stresses in the difference equations in order to update u, v, and I. A special check feature is also employed: If the sign of the velocity difference between two adjacent cells changes during a time step, then we set the corresponding driving force to zero* within the time step when this occurs (actually accomplished by using the average driving force for the entire step). This is called an overshoot correction and serves to avoid cell-to-cell oscillations in the velocity.

The need to save old and new velocities for some cells and the provision to prevent overshoot offer some special problems in the programming. In the present version, the procedure which is used involves working on three rows of cells in each sweep. In the most advanced row, stresses are computed from the old velocities and tentative values of Δu, Δv are computed. In the second row, for the cell immediately below, the tentative Δu, Δv are finalized unless overshoot occurs. Overshoot is checked at the upper and right boundaries and for the hoop stress

---

*Similarly, for the hoop stress, the driving force is set to zero within the time step when the sense of the corresponding strain-rate term, ε_{33}, changes.

and is prevented by reduction of the appropriate driving stresses, as described above. Finally, ΔI is computed for this second row cell, using the final values of the stresses. This ΔI calculation requires old velocities from the surrounding cells, necessitating retention of these velocities for the third row of cells. Special procedures are used for those cells lying on the grid boundaries.

Notes explaining various portions of the code are also given in the FORTRAN listings of Section IV.

Timings to date of computations using the strength or viscosity options indicate that such problems are a factor of two longer in computer time than equivalent hydrodynamics problems without these effects.

The main logic for the strength or viscosity is done in subroutine PH3. In addition, PH3 refers to the following subroutines:

GRADR	Calculates the velocity gradients at the right boundary of the cell in question.
GRADZ	Calculates the velocity gradients at the top boundary of the cell in question.
STRESR	Calculates the two stresses (normal and shear) at the right boundary of the cell in question.
STRESZ	Calculates the two stresses (normal and shear) at the top boundary of the cell in question.
HOOP	Calculates the hoop stress for the cell in question.
DELTAU	Calculates the radial acceleration of the cell in question due to stress forces.
DELTAV	Calculates the axial acceleration of the cell in question due to the stress forces.
ECALC	Calculates the change of the specific internal energy of the cell in question due to the work done by the stress forces.

In addition to the normal input required for OIL,[4] the strength version requires the following additional quantities:

Location	Symbol	Description
21	AMDM	Cutoff for strength based on density; if $\rho_{(K)} <$ AMDM ρ_0, forces due to strength are not applied on cell K.
25	FeF	Flag, if = 0., PH3 (the strength subroutine) will be called, if $\neq$ 0, no strength.
49	i3	The number of times to subcycle through the strength routine (time step $\Delta t/i3$, where Δt is the hydro time step used in PH1 and PH2).
66	DXN	Cutoff for the stresses.
71	RSTOP	The factor to multiply the equation-of-state constants by to convert units to cgs system.
72	SHELL	The factor to multiply the coefficient of pressure in the speed-of-sound calculation.
107	Z(107)	Velocity gradient cutoff.
5841	DDXN	K_0 = yield strength, in the appropriate units.
5843	DKE	η_0 = Newtonian viscosity coefficient, in the appropriate units.
8517	TABLM	Factor on dV/dz critical, shifts the point where the full yield strength is applied.
13583	VT	Minimum ρ to trigger rezone.
13586	VVABOV	Epsilon for energy cutoff, to cut down on the precursor.
13587	VVBLO	Epsilon for velocity cutoff, to cut down on the precursor.

The code is currently being modified to incorporate all the strength constants and flags on the dump tape. Until this is completed, the various quantities, such as DDXN, DKE, TABLM, VVABOV, VVBLO, and VT, must be loaded on every restart.

3.4. OTHER GENERALIZATIONS OF OIL

Two additional modifications have been made to improve OIL. One is the capability of treating two-dimensional x-y flows as well as axisymmetric ones. The other is an improved representation of free surfaces that distinguishes between condensed and vaporized materials and provides an improved transport scheme for the condensed case. These two modifications are described below.

3.4.1. Axisymmetric and Plane Flows

Whether a problem is to be in axisymmetric or plane coordinates is designated by a single flag. If CLAM is used to generate the problem, this flag is the fourth word of card number 2 (input cards for CLAM) and is 0. for axisymmetric geometry, and any number other than 0. is used to designate x-y Cartesian geometry.

When the CLAM code is used, the changes required are listed below. The referenced card numbers and pages are described in Ref. 4.

The following statements replace the cards labelled 1790 through 1810 in the input subroutine (page 77):

```
      IF (Q000FL) 3000, 3002, 3000
3000  TAU(i) = Dx(1)
      WS = 1.
      GO TO 1008
3002  WSB = WSA
      WSA = x(i) * * 2
      TAU(i) = WS* (WSA-WSB)
1008  CONTINUE
```

Replace cards numbered 1250 through 1260 in the routine PH3 (page 89) by:

```
      IF (Q000FL) 6000, 6001, 6000
6000  TAM = WS5 * Dy(j)/FMX
```

```
        GO TO 6002
   6001 T.\M = WPIDy * WS5 * Dy(j)
   6002 E = 0.0
```

Replace card number 2050 in routine PH3 (page 91) by:

```
        IF (Q000FL) 6004, 6005, 6004
   6004 AM(n) = TAM * WSR
        GO TO 4341
   6005 AM(N) = TAM * TX * WSR
```

After statement 7162 (card number 1380) in routine Output (page 100) insert

```
        GAM = Q00FL
```

If the subroutine SETUP is used to generate the problem, then the flag is located in the variable GAM (location 10 for the CARDS routine).

Referring to Eqs. (1) through (4) of Ref. 4, Eq. (1) is changed to

$$\frac{\partial \rho}{\partial t} = - \frac{\partial \rho u}{\partial r} - \frac{\partial \rho v}{\partial z} ;$$

the two momenta equations remain unchanged; and for Eq. (4),

$$\rho \frac{\partial E}{\partial t} = - \frac{\partial P u}{\partial r} - \frac{\partial P v}{\partial z} .$$

3.4.2. Free Surface Modification

A modification has been made to the scheme of handling free surfaces in the transport routine of OIL. As reported in Ref. 4, the OIL write-up, a velocity change in the projectile was the criterion for ensuring that the bottom of the projectile empty properly as it continues to move upward. However, this scheme was not operative after the reflected shock broke through the bottom surface of the projectile.

The new scheme is, again, concerned with the emptying of cells. The criterion for applying the scheme is that the energy of the cell be less

than the energy required to vaporize the material. Thus, if the material is a gas, no special modification is required if the material is a solid, the transport is done using the density and velocity of the receptor cell.

Another feature of the code is the ability to convert to the cgs units. Two additional input numbers are required, RSTOP and SHELL. Their definitions are listed in the revised Common list in Section IV.

3.5. TEST PROBLEMS

A number of test problems have been computed during the course of the present code development, and in this section some representative results are presented. It is expected that extensive application of the code to impact problems, and the associated discussion of impact mechanics, will be the subject of future reports.

Two one-dimensional impacts have been computed in which wax plates strike wax targets at a velocity of 3.5×10^4 cm/sec. One of these impacts was treated using the unmodified OIL hydrodynamics code and the second was a viscous flow problem with viscosity $\eta_0 = 2 \times 10^5$ ergs sec/cm^3. Cell dimensions in the two problems were 1 cm. The most interesting results of the calculations are the pressure-pulse and velocity-pulse profiles seen in Figs. 4 and 5. The viscous version of the problem is seen to be effective in eliminating the oscillations which are characteristic of the unmodified version. Some viscous smearing of the shock front is also evident.

Two axisymmetric wax-on-wax impacts were also computed, with an impact velocity of 4×10^5 cm/sec. One was run with the hydrodynamic version of the code, which differs from previous calculations of this impact only in the improved treatment of the free surface (Section 3.4.) and a somewhat coarser zoning. The other impact was treated as a problem in viscous flow with viscosity 1×10^4 ergs sec/cm^3. Initial cell size in both problems was 0.0525 cm. Successive stages of the viscous

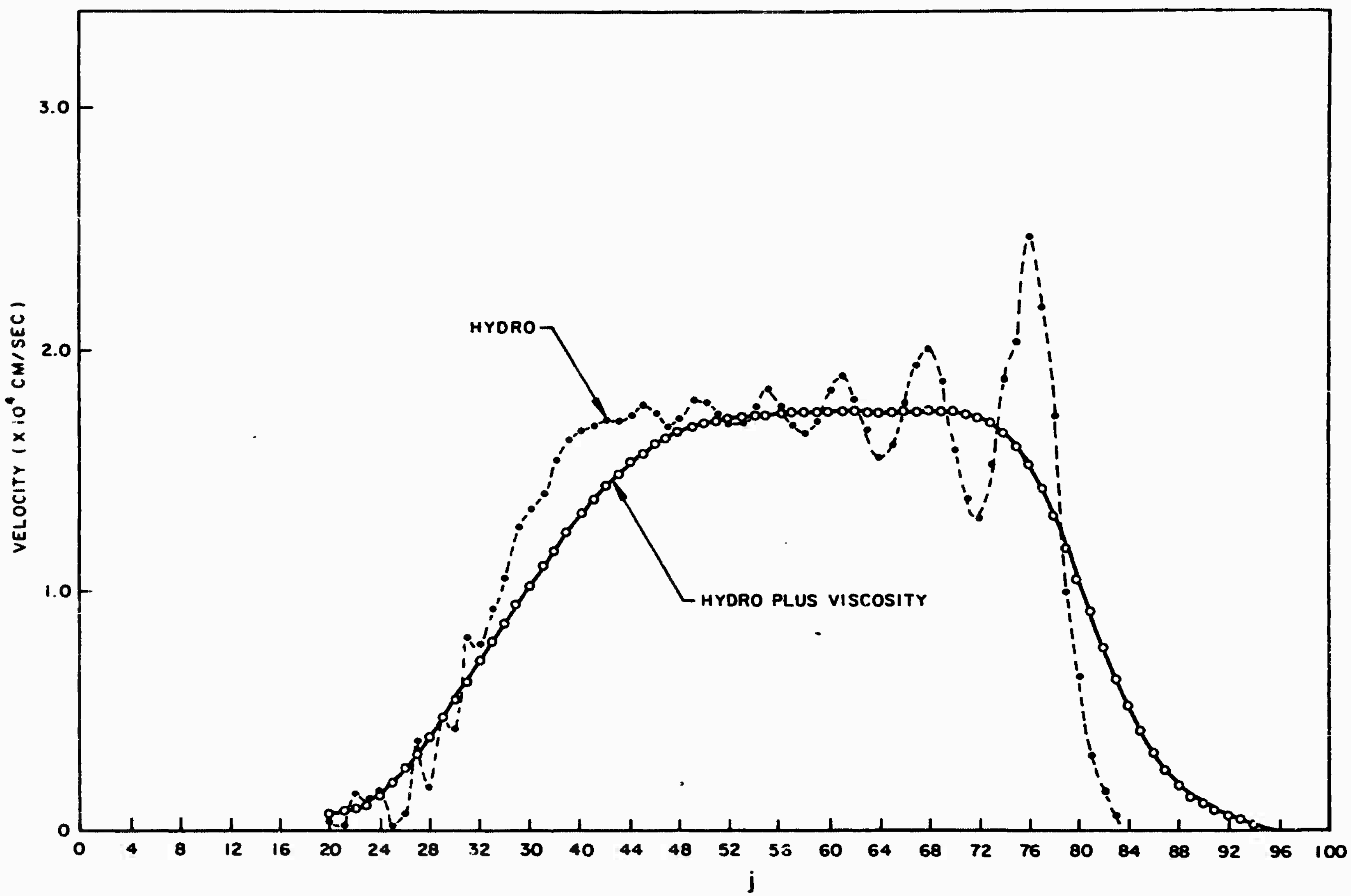

Fig. 4--Velocity profiles for the purely hydrodynamic and viscous-hydrodynamic versions of OIL, in the case of a slab-geometry impact

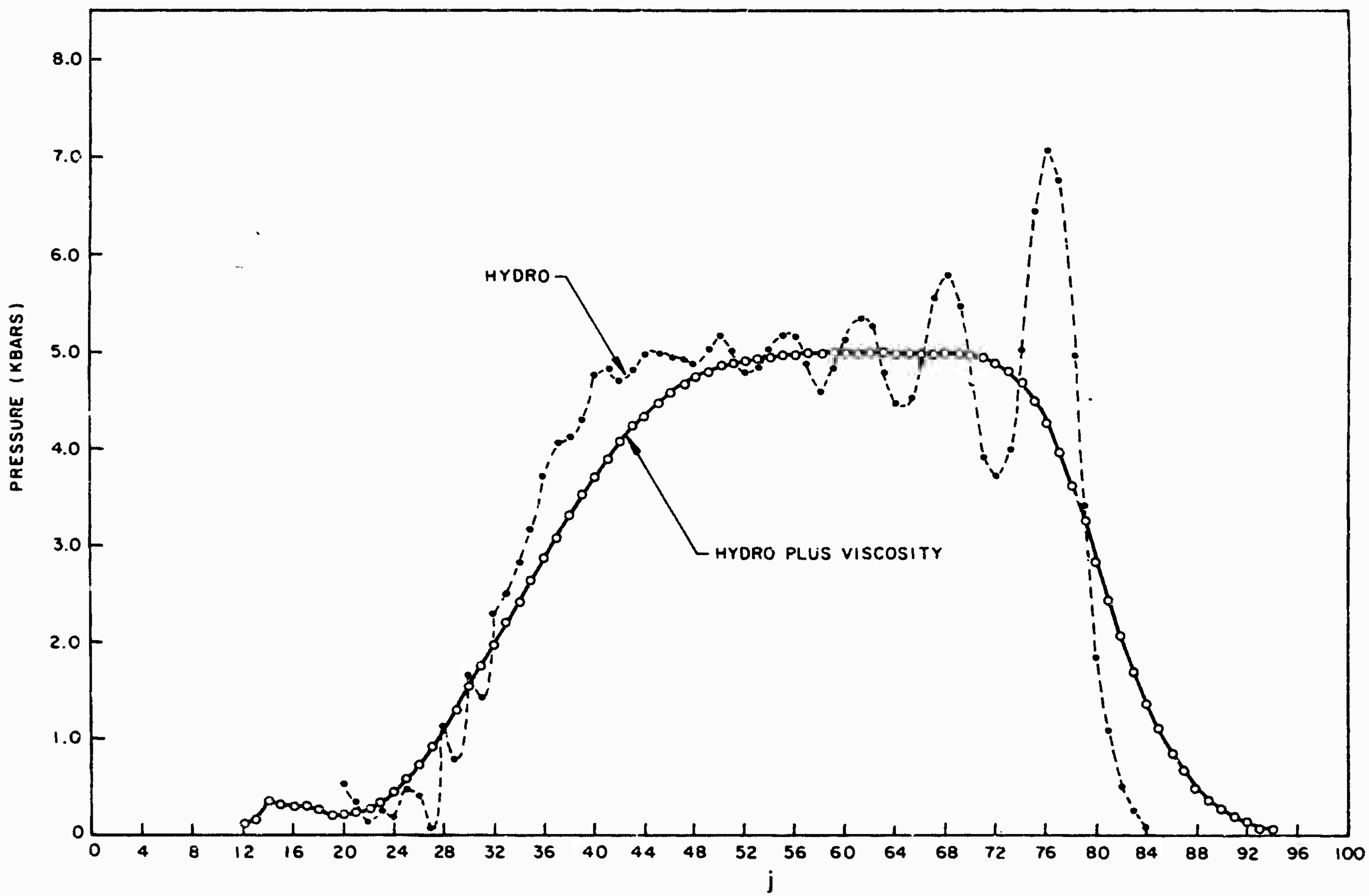

Fig. 5--Pressure profiles for the purely hydrodynamic and viscous-hydrodynamic versions of OIL, in the case of a slab-geometry impact

flow are given in Fig. 6, and the crater growth in these two problems is compared in the mass distribution plots of Figs. 7 and 8. It is seen that the gross features of the mass motion are in very good agreement with the experimental crater growth data by Karpov,[6] especially for the viscous flow. The viscosity problem is also in better agreement with the experimental shock-pressure-attenuation data,as can be seen from Fig. 9. The results are merely illustrative of the code, however, since no attempt has been made to formulate a realistic constitutive equation for wax.

The above axisymmetric impact was also run as a problem in strength-dependent deformation using the Prandtl-Reuss constitutive equations described in previous sections. A modification to this representation was included in order to reduce the yield strength as the velocity gradients became small and thus to avoid oscillations in the form of overcorrections. The results were very satisfactory at high pressures but still exhibited some oscillatory behavior as pressures became comparable to the yield strength, which was taken to be 5 kbars in this exploratory calculation.

A spherically symmetric test problem was computed in cylindrical coordinates in order to test the strength code against preferential treatment in the axial and radial directions. A hot sphere of plastic (density 0.92 g/cm^3 and specific energy 7×10^{10} ergs/g, sufficient to exert a pressure of 103 kbars) was allowed to explode in a cold plastic atmosphere (density 0.92 g/cm^3, zero pressure and energy). A yield strength of 5 kbars was assumed, and this yield strength was again diminished as velocity gradients became small. Figures 10 and 11 bear out the spherical character of the solution. Similar tests of sphericity have previously been reported[4] for the purely hydrodynamic part of the code.

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[6] B. G. Karpov, "Transient Response of Wax Targets to Pellet Impact at 4 km/sec," Ballistic Research Laboratories, Report No. 1226, October, 1963.

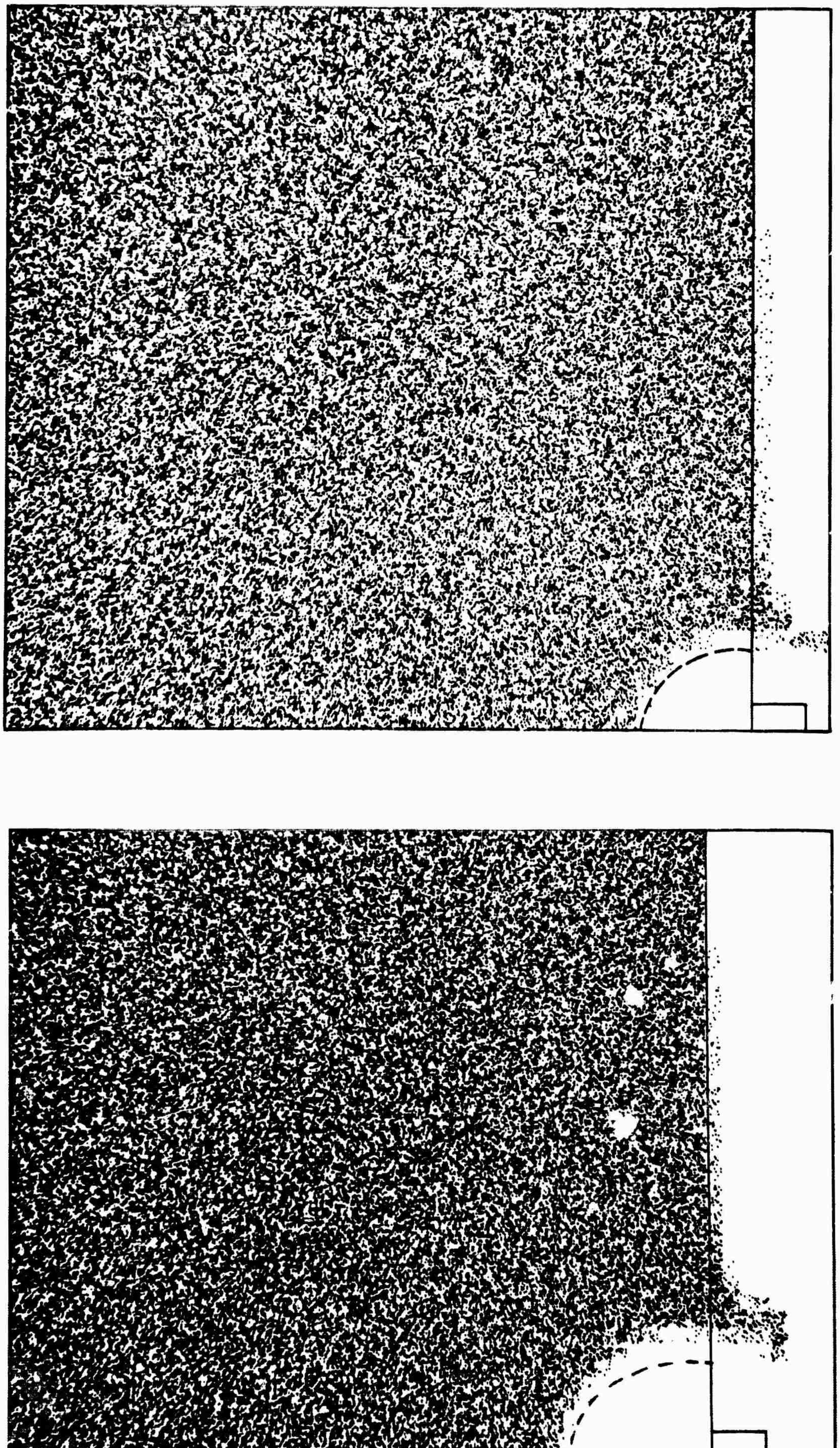

Fig. 7--Successive stages in the viscous-hydrodynamic axisymmetric impact

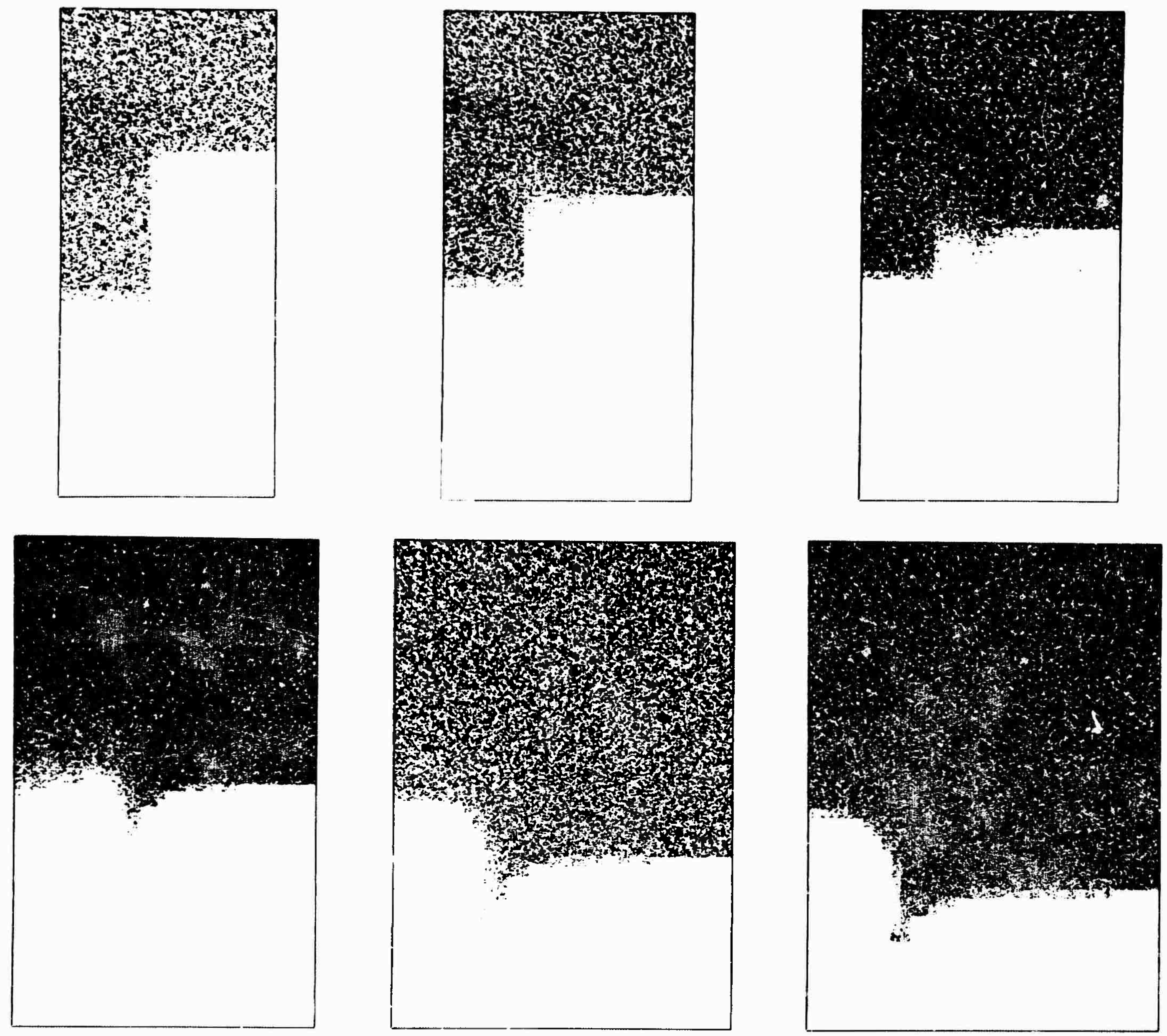

Fig. 6--Mass distribution plots for the purely hydrodynamic axisymmetric impact problem. The dashed profile is an experimental curve.

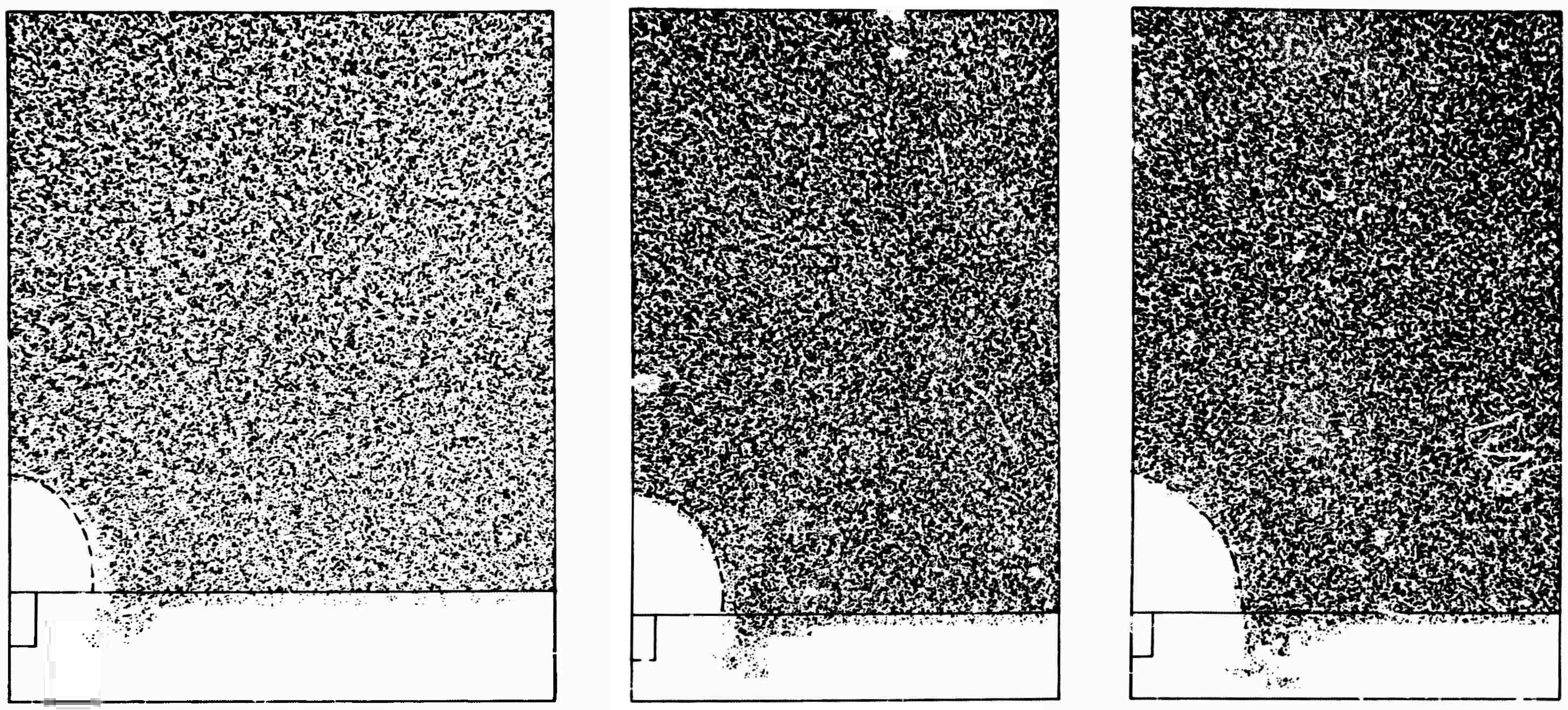

Fig. 8--Mass distribution plots for the viscous-hydrodynamic axisymmetric impact problem. The dashed profile is an experimental curve.

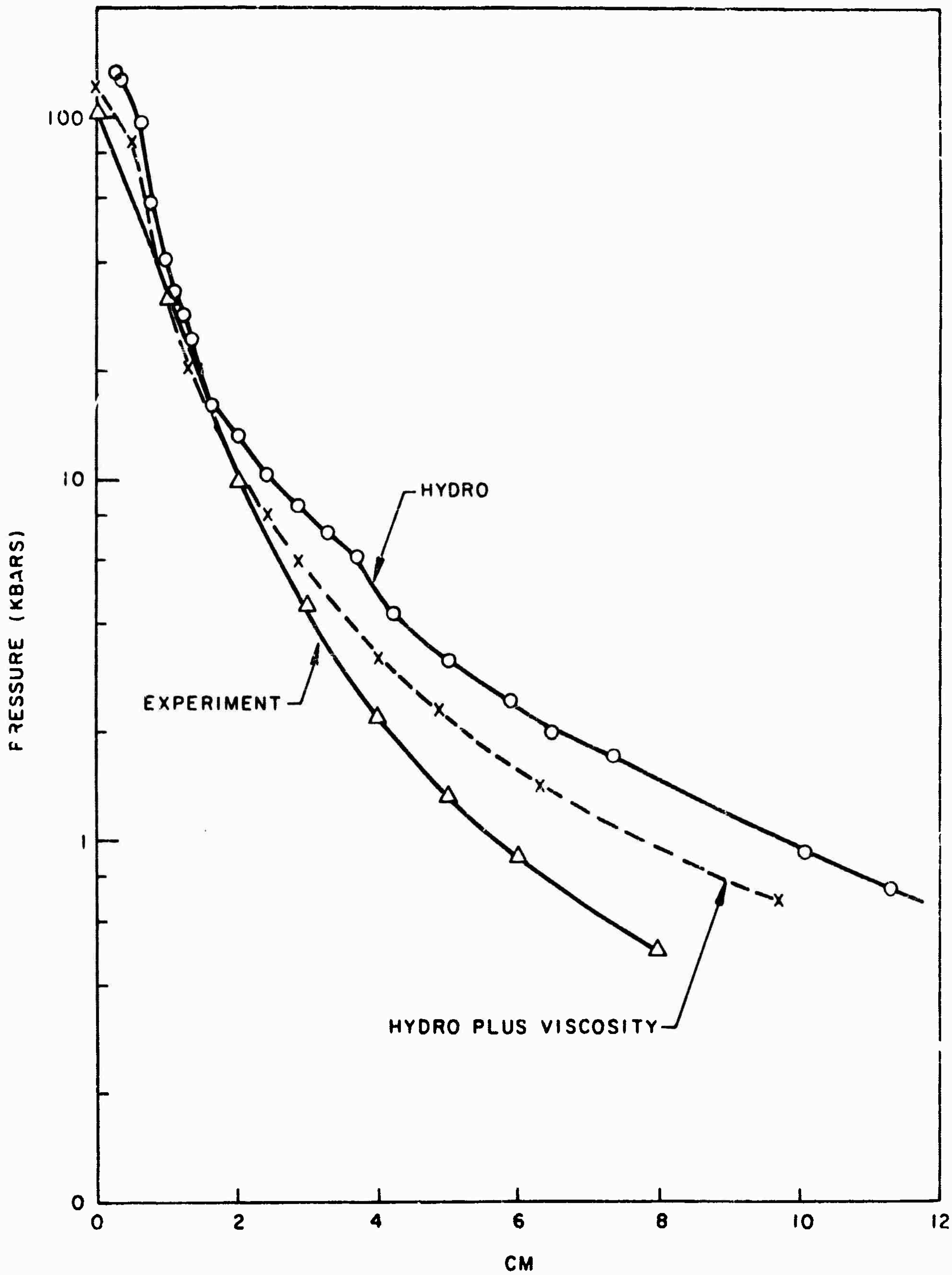

Fig. 9--Experimental, hydrodynamic, and viscous-hydrodynamic shock attenuation curves for wax

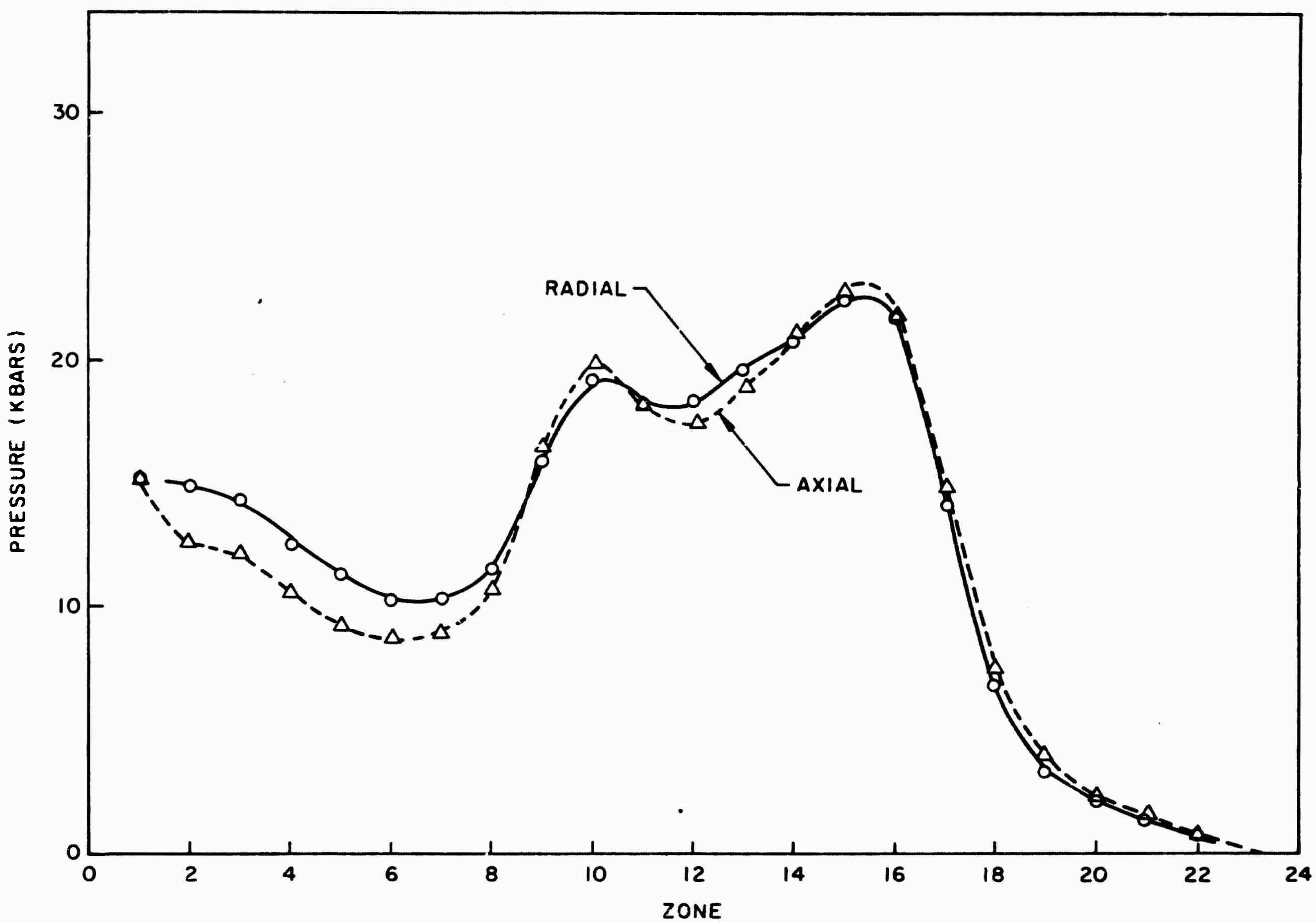

Fig. 10--Computed pressure profiles in the axial and radial directions, for the spherically symmetric problem as treated in cylindrical coordinates

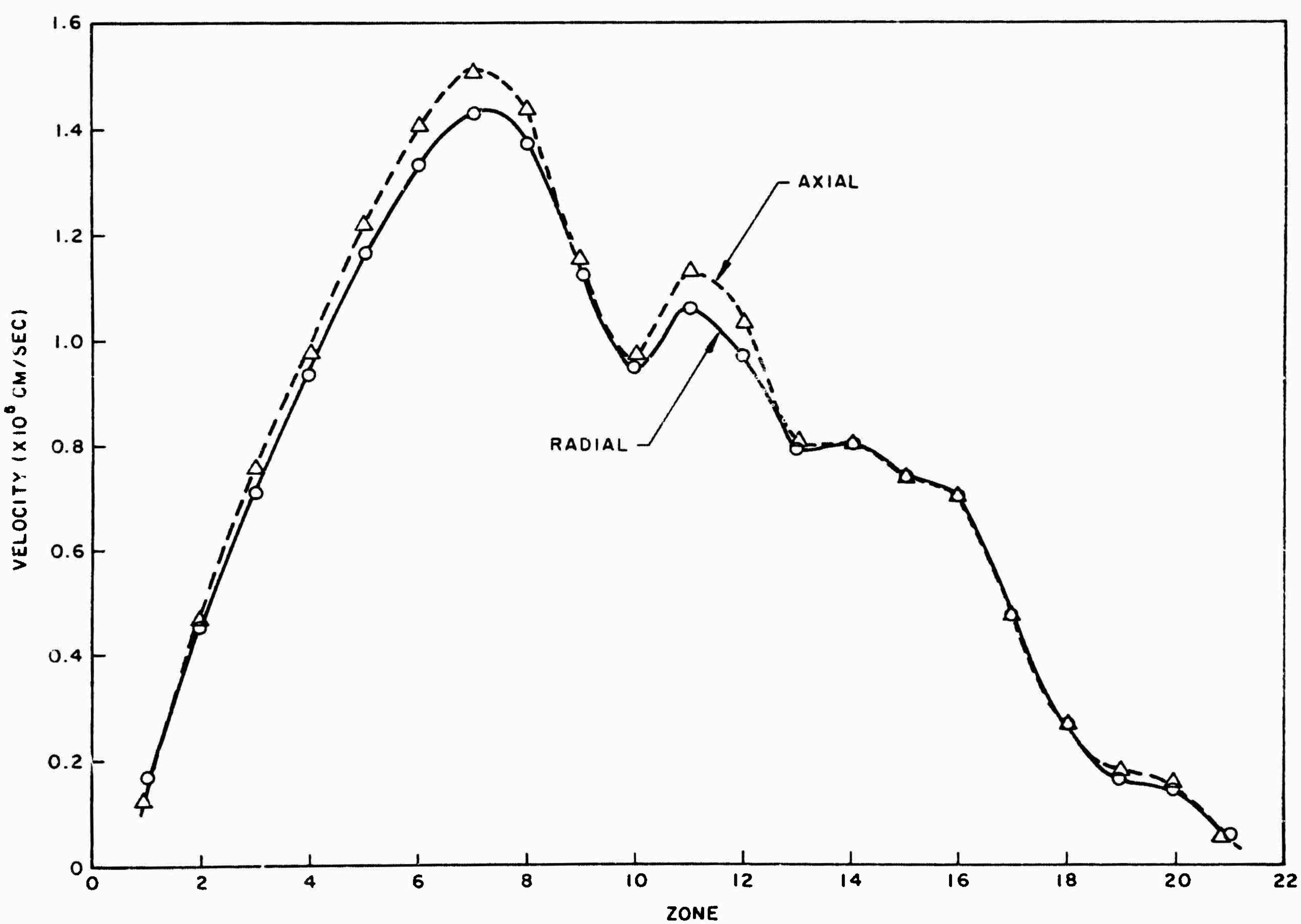

Fig. 11--Computed velocity profiles in the axial and radial directicns, for the spherically symmetric problem as treated in cylindrical coordinates

IV. LIST OF REVISED COMMON AND FORTRAN LISTINGS FOR OIL WITH STRENGTH AND VISCOSITY

In the following list of the revised Common, location refers to the location of that symbol relative to the begining of Common. Since the beginning of Common is assigned the same location for each subroutine, a program (CARDS) is available for changing any word in Common.

If changes are made in the length of the dimensional arrays, it will be necessary to change the locations in the following Common list.

The revised FORTRAN listing for OIL follows the revised Common. Note that the C's denoting explanatory remarks are at the far left margin.

REVISED COMMON

Symbol	Location	No. of Words	Units	Description
XX	151	53	cm	XX(2) = X(1)
UR	205	200	None	Note the many equivalence statements
PR	405	200	None	Note the many equivalence statements
YY	605	101	cm	YY(2) = Y(1)
AID	706	1	None	Not used, this is a single material code
AIX	707	2500	jerks or ergs/gram	Specific internal energy (X) for cell (K)
AM	3207	130	None	Mass of particle (N) for SHELL code
AMD	3337	1	None	Not used, this is a single material code
AMX	3338	2500	grams	Total (X) mass in cell (K)
AREA	5838	1	None	Tag, used in PH2
BIG	5839	1	sh^{-1} or sec^{-1}	= dV/dZ critical, computed in PH3
BOUNCE	5840	1	None	Tag used in PH2
DDXN	5841	1	ergs or jerks/cm^3	= yield strength for the material
DDVK	5842	1	ergs or jerks/cm^3	= hoop stress for cell (K)
DKE	5843	1	ergs or jerks /cm^3 sec or sh	= η_0 = the coefficient of viscosity
DVK	5844	1	sec^{-2} or sh^{-2}	= DDXN /[ρ_0 DX^2]
DX	5845	52	cm	DX(i) = X(i) - X(i-1)
DY	5897	100	cm	DY(j) = Y(j) - Y(j-1)
E	5997	1	None	Used in hoop routine
FD	5998	1	None	Used in hoop routine
FS	5999	1	None	Flag in PH2
FX	6000	1	None	Not used
OUT	6001	1	None	Tag in particle PH2
P	6002	2500	jerks or ergs/cm^3	Material pressure in cell (K)
PABOVE	8502	1	jerks or ergs/cm^3	= [P(K) + P(cell above)]/2
PBLO	8503	1	jerks or ergs/cm^3	= [P(K) + P(cell below)]/2
PIDTS	8504	1	1/cm sh	1./[Δt π DY(j)] in PH1, 1./$\pi\Delta t$ in PH2
PPABOV	8505	1	None	Not used

PRR	8506	1	jerks or ergs/cm^3	= [P(K) + P(cell to the right)]/2
PUL	8507	1	None	Not used
QDT	8508	1	None	Not used
RC	8509	1	cm	[X(i) + X(i-1)]/2. in PH1
ReZ	8510	1	None	If material leaves grid in PH2, ReZ set = 1.
RHO	8511	1	gm/cm^3	Density of material in a cell
RL	8512	1	None	Not used
RR	8513	1	cm	= [X(i) + X(I+1)]/2. in PH1
SIG	8514	1	cm	Minimum ΔX or ΔY in CDT routine
QOOOFL	8515	1	None	Not used
SWITCH	8516	1	None	Not used
TABLM	8517	1	None	Factor on dV/dZ critical
TAU	8518	52	cm^2	= π $(X(i)^2 - X(i-1)^2)$ = area in Z direction
TAUDTS	8570	1	cm^2(sh or sec)	= TAU(i) Δt in PH1
TAUDTX	8571	1	None	Not used
U	8572	2500	cm/sh or/ sec	= R component of velocity in cell (K)
UK	11072	1	cm/sh or/ sec	= R component of velocity in cell (K) used in SHELL transport
URR	11073	1	cm^2/sh or/ sec	= [U(K) RC + U(K+1) RR]/2.
UT	11074	1	None	Signal in PH1, decrease Δt next pass
UU	11075	1	sh or sec	New Δt in PH1, for integrating backwards
UUU	11076	1	None	Used in PH3
UTEF	11077	1	cm/sh or/ sec	R velocity component used to move particles in SHELL
UVMAX	11078	1	sh^{-1} or sec^{-1}	|Max velocity| /Min (ΔX or ΔY)
V	11079	2500	cm/sh or/ sec	Axial (Z) component of velocity for cell (K)
VABOVE	13579	1	cm/sh or/ sec	[V(K) + V(cell above)]/2.
VBLO	13580	1	cm/sh or/ sec	[V(K) + V(cell below)]/2.
VEL	13581	1	None	Used as tag in PH1 and PH2

VK	13582	1	cm/sh or/ sec	Axial component of velocity in cell (K) for SHELL
VT	13583	1	$gram/cm^3$	Rezone trigger set if mass of ρ=VT leaves the grid
VTEF	13584	1	cm/sh or sec	Z velocity component used to move particles in SHELL
VV	13585	1	None	Used in PH3
VVABOV	13586	1	jerks/gram or ergs/gram	Minimum specific internal energy allowed as a result of PH3
VVBLO	13587	1	cm/sh or sec	Minimum velocity allowed as a result of PH3
W2	13588	1	None	Not used
W3	13589	1	None	Not used
WPS	13590	1		Working Storage
WS	13591	1		
WSA	13592	1		
WSB	13593	1		
WSC	13594	1		
XL	13595	130	cm	R coordinate of particle N
XLF	13725	1	None	Used in velocity weighting for SHELL transport
XN	13726	1	cm	R coordinate of particle N at cycle (n-1)
XR	13727	1	None	Used in velocity weighting for SHELL transport
YL	13728	130	cm	Z coordinate of particle N
YLW	13858	1	None	Used in velocity weighting for SHELL transport
YN	13859	1	cm	Z coordinate of particle N at cycle (n-1)
YU	13860	1	None	Used in velocity weighting for SHELL transport
ZMAX	13861	1	cm	The largest Z value of any particle in SHELL transport
i	13862	1		Indices (working storage)
ii	13863	1		
iN	13864	1		
iR	13865	1		
iWS	13866	1		

iWSA	13867	1		Indices (working storage)
iWSB	13868	1		
iWSC	13869	1		
iW1	13870	130	None	i of the cell (K) where particle (N) is for SHELL transport
j	14000	1		Indices (working storage)
jN	14001	1		
jP	14002	1		
jR	14003	1		
K	14004	1	None	Index of cell defined such that $K = (j-1)\ iMAX + i+1$
KN	14005	1		Indices (working storage)
KP	14006	1		
KR	14007	1		
KRM	14008	1		
L	14009	1		
M	14010	1		
MA	14011	1		
MB	14012	1		
MC	14013	1		
MD	14014	1		
ME	14015	1		
MZ	14016	1	None	Set by input, for length of Z block, also used in EDIT
N	14017	1		Indices (working storage)
NK	14018	1		
NKMAX	14019	1		
NK1	14020	1		
NO	14021	1		
NR	14022	1	None	Maximum number of radiation cycles/hydro $NR \leq NRM$
iW2	14023	130	None	= (j) value of cell (K) where particle (N) is used in SHELL transport
X	152	53	cm	X(i) = right dimension of zone (i,j)

UL	205	200		Note the equivalence statements
FLEFT	205	200		
YAMC	304	100		
SIGC	504	100		
PL	405	200		
GAMC	405	100		
TAB	205	15		
AMK	220	15		
PK	235	15		
QK	250	15		
Y	606	100	cm	Y(j) = top dimension of zone (i,j)
ASN	3207	52		Array for normal stress at top
AST	3259	52		Array for shear stress at top
ASNB	13595	52	Note	Array for normal stress at bottom
ASTB	13647	52	the	Array for shear stress at bottom
RSN	13728	52	equivalence	Array for normal stress at the right
RST	13780	52	statements	Array for shear stress at the right
SIG33	13870	52		Array for hoop stress
DUDOT	13922	52		Array for the R component of acceleration
DVDOT	14023	52		Array for the Z component of acceleration
DAIX	14075	52		Not used
KL	14009	1		Note the equivalence statements
KAR	14010	1		
KA	14011	1		
KAL	14012	1		
KBR	14013	1		
KB	14014	1		
KBL	14015	1		

Location	Symbol	Units	Description
Z(1)	PROB	-	Problem number (if positive, this is an OIL run; If negative, this is a SHELL run.)
Z(2)	CYCLE	-	Cycle number (floating point value)
Z(3)	DT	sh. or sec	Δt hydro = $t^n - t^{(n-1)}$
Z(4)	PRINTS	-	Cycle frequency for short print
Z(5)	PRINTL	-	Cycle frequency for long print
Z(6)	DUMPT7	-	Cycle frequency for binary tape dumps
Z(7)	CSTOP	-	Cycle number at which problem will stop
Z(8)	PIDY	-	$\pi = 3.1415927$
Z(9)	TMZ	gm	Total (x + ·) mass at t = 0 (calculated in CLAM code.)
Z(10)	GAM	-	If = 0. (cylindrical geometry); otherwise Cartesian
Z(11)	GAMD	-	$1./(\gamma_{\cdot}-1.)$ computed in input routine
Z(12)	GAMX	-	$1./(\gamma_x - 1.)$ computed in input routine
Z(13)	ETH	jerk or erg	Total energy (computed in CLAM for t = 0). Changed in PH1 at transmittive boundaries and in PH2 as mass leaves the grid.
Z(14)	FFA	-	Upper limit for stability and used to calculate Δt, only if CABLN = 0.
Z(15)	FFB	-	Lower limit for stability and used to calculate Δt, only if CABLN = 0.
Z(16)	TMDZ	gm	Total (·) mass at t = 0, calculated in CLAM code
Z(17)	TMXZ	gm	Total (x) mass at t = 0, calculated in CLAM code
Z(18)	XMAX	cm	= x(iMAX)
Z(19)	TXMAX	cm	2(XMAX) at t = 0, calculated in CLAM code
Z(20)	TYMAX	cm	2(YMAX) at t = 0, calculated in CLAM code
Z(21)	AMDM	-	If the density of a cell is less than AMDM times the initial density (ρ_0), strength is bypassed for this cell
Z(22)	AMXM	gm	Minimum particle (x) mass/2. calculated in CLAM
Z(23)	DNN	-	$(ETH - E)^{N-NPC}/ETH$
Z(24)	DMIN	-	If (ECK) > DMIN, problem will stop and the edit routine will call dump
Z(25)	FeF	-	Flag for omitting strength
Z(26)	DTNA	sh. or sec	Δt^{n-1}

Location	Symbol	Units	Description
Z(27)	CVIS	-	If < 0, bottom boundary is transmittive; otherwise it is reflective.
Z(28)	NPR	-	Index (working storage)
Z(29)	NPRi	-	Index (working storage)
Z(30)	NC	-	Cycle number (fixed point)
Z(31)	NPC	-	Number of cycles between short prints
Z(32)	NRC	-	Index
Z(33)	iMAX	-	Maximum number of zones in the R direction
Z(34)	iMAXA	-	iMAX + 1
Z(35)	jMAX	-	Maximum number of zones in the Z direction
Z(36)	JMAXA	-	jMAX + 1
Z(37)	KMAX	-	(iMAX)(jMAX) + 1
Z(38)	KMAXA	-	KMAX + 1
Z(39)	NMAX	-	Total number of particles + 1, generated in CLAM, for SHELL problems only.
Z(40)	ND	-	Total number of (·) particles + 1, generated in CLAM
Z(41)	KDT	-	If = 0, Δt has changed, if $\neq$ 0, Δt remains constant
Z(42)	ixMAX	-	Not used
Z(43)	NOD	-	Index
Z(44)	NOPP	-	Index
Z(45)	NiMAX	-	New iMAX before adding new zones
Z(46)	NjMAX	-	New jMAX before adding new zones
Z(47)	i1	-	Maximum i disturbance
Z(48)	i2	-	Maximum j disturbance
Z(49)	i3	-	Not used
Z(50)	i4	-	Not used
Z(51)	N1	-	Scratch tape number for particles if this is a SHELL run
Z(52)	N2	-	Scratch tape number for particles if this is a SHELL run
Z(53)	N3	-	Number of particle records generated if this is a SHELL run
Z(54)	N4	-	Number of particles - 1 per record (MAX = 127) if this is a SHELL run
Z(55)	N5	-	Not used

Location	Symbol	Units	Description
Z(56)	N6	-	Number of particles on last particle record if this is a SHELL run
Z(57)	N7	-	Not used
Z(58)	N8	-	Not used
Z(59)	N9	-	Not used
Z(60)	N10	-	= i value of zone that is controlling Δt
Z(61)	N11	-	= j value of zone that is controlling Δt
Z(62)	NRM	-	= maximum number of radiation cycles/hydro cycle, input number
Z(63)	TRAD	sh.	= NR$\cdot\Delta$t RAD = Δt HYDRO
Z(64)	XNRG	jerk or erg	Total energy of (x) material
Z(65)	SN	-	If = 0, code will decrease Δt to correct for $I < 0$, otherwise those $I < 0$ are left alone
Z(66)	DXN	-	Cutoff for the stresses
Z(67)	RADER	gm-cm/sh	Total positive radial momentum ((x) only)
Z(68)	RADET	"	Total positive axial momentum ((x) only)
Z(69)	RADEB	"	Total positive radial momentum (x) for material under the target
Z(70)	DTRAD	-	Not used
Z(71)	REZFCT	-	If = 0, 1H2 will not trigger rezone.
Z(72)	RSTOP	-	Factor for converting units for energy
Z(73)	SHELL	-	Factor for converting units for speed of sound calculation
Z(74)	BBOUNL	-	Not used in this version
Z(75)	TOZONE	gm/cm^3	Minimum density for mass flow at the free surface. The mass flux is held up unless it produces a density that is > than TOZONE
Z(76)	ECK	-	$\left[\left(\frac{ETH - E}{ETH}\right)^{N} - \left(\frac{ETH - E}{ETH}\right)^{N-NPC}\right] \Big/ NPC$
Z(77)	SBOUND	-	Fraction of Λ in mass weighting velocity
Z(78)	X1	cm/sh^2	Acceleration (R direction) due to the stresses
Z(79)	X2	cm/sh^2	Acceleration (Z direction) due to the stresses
Z(80)	Y1	-	Not used
Z(81)	Y2	-	Not used

Location	Symbol	Units	Description	
Z(82)	CABLN	-	If < 0, code controls Δt but, at Z(139) of instability	
Caution: You must load a Δt for this option.			If = 0, code controls the Δt, decreasing Δt if $\left\lvert\frac{U\Delta t}{\Delta x}\right\rvert$ or $\left\lvert\frac{V\Delta t}{\Delta y}\right\rvert$ exceed FFA and increasing Δt if less than FFB	
This holds if SN $\neq$ 0			If greater than 0, Δt will remain constant	
Z(83)	VISC	jk/g	The change (ΔI) due to the stresses	
Z(84)	T	sh or sec	Total time up to cycle N, $t^n = t^{n-1} + \Delta t$	
Z(85)	GMAX	-	Maximum of γ_x or $\gamma_.$	
Z(86)	WSGD	-	$\gamma_.$	
Z(87)	WSGX	-	γ_x and (γ_{max}-1) in the CDT routine	
Z(88)	GMADR	-	$\gamma_./(\gamma_.-1.)$	
Z(89)	GMAXR	-	$\gamma_x/(\gamma_.-1.)$	
Z(90)	S1	sh^{-1} or sec^{-1}	du/dR	Velocity gradients at the right boundary of cell (K)
Z(91)	S2	"	dv/dR	
Z(92)	S3	"	du/dZ	
Z(93)	S4	"	dv/dZ	
Z(94)	S5	"	u/R	
Z(95)	S6	"	du/dZ	Velocity gradients at the top boundary of cell (K)
Z(96)	S7	"	dv/dZ	
Z(97)	S8	"	du/dR	
Z(98)	S9	"	dv/dR	
Z(99)	S10	"	u/R	
Z(100)		g	Mass thrown away (PH2) if any cell has a ρ < TOZONE	
Z(101)		jk or erg	Total energy of this mass thrown away.	
Z(102)		g-cm/sh	Total radial momentum of this mass thrown away	
Z(103)		"	Total axial momentum of this mass thrown away	
Z(104)		jk or erg	Energy (internal) added to system when the internal is set to 0. if I < 0. (PH2)	
Z(105)	SNL	jk or erg/cm^3	The normal stress at the left boundary of cell (K)	
Z(106)	STL	"	The shear stress at the left boundary of cell (K)	
Z(107)		sh^{-1} or sec^{-1}	Velocity gradient cutoff	

Location	Symbol	Units	Description	
Z(108)		-	Not used	
Z(109)		-	Not used	
Z(110)		jk or erg/g	Critical energy E_S, same value as Z(122) used in PH2	
Z(111)		g/cm^3	Initial density (ρ_0) of the material	
Z(112)		cm/sh or sec	Initial velocity of the projectile	
Z(113)		-	Not used	
Z(114)		-	Not used	
Z(115)		g/cm^3	Density (ρ_0)	
Z(116)		-	a	
Z(117)		jk/g	E_0	
Z(118)		-	b	
Z(119)		jk/cm^3	A	
Z(120)		-	V_S	For equation of state
Z(121)		-	-	
Z(122)		jk/g	E_S	
Z(123)		-	α	
Z(124)		-	β	
Z(125)		-	-	
Z(126)		jk/cm^3	B	
Z(127)	SS1	-		
Z(128)	SS2	-		
Z(129)	SS3	-		
Z(130)	SS4	-		
Z(131)	SS5	-		
Z(132)	SS6	-	Not used	
Z(133)	SS7	-		
Z(134)	SS8	-		
Z(135)	SS9	-		
Z(136)	SS10	-		
Z(137)	SS11	-		
Z(138)		g/cm^3	Density check; if $\rho(K) < Z(138)$, the stability check for cell (K) is bypassed	

Location	Symbol	Units	Description
Z(139)		-	Percent of instability, used in CDT if CABLN < 0
Z(140)	SNR	jk or erg/cm^3	The normal stress at the right boundary of cell K
Z(141)	STR	"	The shear stress at the right boundary of cell K
Z(142)	SNT	"	The normal stress at the top boundary of cell K
Z(143)	STT	"	The shear stress at the top boundary of cell K
Z(144)	SNB	"	The normal stress at the bottom of cell K
Z(145)	STB	"	The shear stress at the bottom of cell K
Z(146)		-	Not used
Z(147)		-	The j interface (projectile-target)
Z(148)	A	10^5cm/sec	$C = A + BP^{\epsilon}$ where $A = C_0$ and P is pressure in megabars
Z(149)	B	-	
Z(150)	ϵ	-	

REVISED FORTRAN LISTING

FOR OIL

```
$IBFTC MAIN     LIST,DECK,REF
C                 D   I   M   E   N   S   I   O   N                       PH2 0020
C                                                                         PH2 0030
       DIMENSION  AM(130),   XL(130),   YL(130),                          PH2 0040
      1 U(2500),V(2500),AMX(2500),AIX(2500),
      2 P(2500),
      3 IW1(130), IW2(130),                                               PH2 0070
      4DX(52),    X(53),     XX(54),    DY(100),   Y(100),    YY(101),    PH2 0080
      5TAB(15),   AMK(15),   PK(15),    QK(15),    Z(150),    J[illegible]150),  PH2 0090
      6TAU(52),   PL(200),   PR(200),   UL(200),   UR(200),               PH2 0100
      7FLEFT(100),YAMC(100), SIGC(100), GAMC(100)                         PH2 0110
       DIMENSION ASN(52),AST(52),ASNB(52),ASTB(52),RSN(52),
      1RSI(52),SIG33(52),DUDOT(52),DVDOT(52),DAIX(52)
       COMMON         Z       ,XX     ,UR     ,PR     ,YY                 PH2 0120
       COMMON         AID     ,AIX    ,AM     ,AMD    ,AMX    ,AREA       PH2 0130
       COMMON         BIG     ,BOUNCE ,DDXN   ,DDVK   ,DKE    ,DVK        PH2 0140
       COMMON         DX      ,DY     ,E      ,FD     ,FS     ,FX         PH2 0150
       COMMON         OUT     ,P      ,PABOVE ,PBLO   ,PIDTS  ,PPABOV     PH2 0160
       COMMON         PRR     ,PUL    ,QDT    ,RC     ,REZ    ,RHO        PH2 0170
       COMMON         RL,RR,SIG,QOOOFL,SWITCH ,TABLM                      PH2 0180
       COMMON         TAU     ,TAUDIS ,TAUDTX ,U      ,UK     ,URR        PH2 0190
       COMMON         UT      ,UU     ,UUU    ,UTEF   ,UVMAX  ,V          PH2 0200
       COMMON         VABOVE  ,VBLO   ,VEL    ,VK     ,VT     ,VTEF       PH2 0210
       COMMON         VV      ,VVABOV ,VVBLO  ,W2     ,W3     ,WPS        PH2 0220
       COMMON         WS      ,WSA    ,WSB    ,WSC    ,XL     ,XLF        PH2 0230
       COMMON         XN      ,XR     ,YL     ,YLW    ,YN     ,YU         PH2 0240
       COMMON         ZMAX    ,I      ,II     ,IN     ,IR     ,IWS        PH2 0250
       COMMON         IWSA    ,IWSB   ,IWSC   ,IW1    ,J      ,JN         PH2 0260
       COMMON         JP      ,JR     ,K      ,KN     ,KP     ,KR         PH2 0270
       COMMON         KRM     ,L      ,M      ,MA     ,MB     ,MC         PH2 0280
       COMMON         MD      ,ME     ,MZ     ,N      ,NK     ,NKMAX      PH2 0290
       COMMON         NK1     ,NO     ,NR     ,IW2                        PH2 0300
C                                                                         PH2 0390
C                                                                         PH2 0400
C                 E   Q   U   I   V   A   L   E   N   C   E               PH2 0410
C                                                                         PH2 0420
      0EQUIVALENCE      (Z,IZ,PROB),       (Z(2),CYCLE),      (Z(3),DT),        PH2 0430
      1(Z(4),PRINTS),   (Z(5),PRINTL),     (Z(6),DUMPT7),     (Z(7),CSTOP),     PH2 0440
      2(Z(8),PIDY),     (Z(9),TMZ),        (Z(10),GAM),       (Z(11),GAMD),     PH2 0450
      3(Z(12),GAMX),    (Z(13),ETH),       (Z(14),FFA),       (Z(15),FFB),      PH2 0460
      4(Z(16),TMDZ),    (Z(17),TMXZ),      (Z(18),XMAX),      (Z(19),TXMAX),    PH2 0470
      5(Z(20),TYMAX),   (Z(21),AMDM),      (Z(22),AMXM),      (Z(23),DNN),      PH2 0480
      6(Z(24),DMIN),    (Z(25),FEF),       (Z(26),DTNA),      (Z(27),CVIS),     PH2 0490
      7(Z(28),NPR),     (Z(29),NPR1),      (Z(30),NC),        (Z(31),NPC),      PH2 0500
      8(Z(32),NRC),     (Z(33),IMAX),      (Z(34),IMAXA),     (Z(35),JMAX),     PH2 0510
      9(Z(36),JMAXA),   (Z(37),KMAX),      (Z(38),KMAXA),     (Z(39),NMAX)      PH2 0520
      0EQUIVALENCE      (Z(40),ND),        (Z(41),KDT),       (Z(42),IXMAX),    PH2 0530
      1(Z(43),NOD),     (Z(44),NOPR),      (Z(45),NIMAX),     (Z(46),NJMAX),    PH2 0540
      2(Z(47),I1),      (Z(48),I2),        (Z(49),I3),        (Z(50),I4),       PH2 0550
      3(Z(51),N1),      (Z(52),N2),        (Z(53),N3),        (Z(54),N4),       PH2 0560
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     4(Z(55),N5),       (Z(56),N6),        (Z(57),N7),        (Z(58),N8),      PH2 0570
     5(Z(59),N9),       (Z(60),N10),       (Z(61),N11),       (Z(62),NRM),     PH2 0580
     6(Z(63),TRAD),     (Z(64),XNRG),      (Z(65),SN),        (Z(66),DXN),     PH2 0590
     7(Z(67),RADER),    (Z(68),RADET),     (Z(69),RADEB),     (Z(70),DTRAD),   PH2 0600
     8(Z(71),REZFCT),   (Z(72),RSTOP),     (Z(73),SHELL),     (Z(74),BBOUND),PH2 0610
     9(Z(75),TOZONE),   (Z(76),ECK),       (Z(77),SBOUND),    (Z(78),X1)       PH2 0620
     OEQUIVALENCE       (Z(79),X2),        (Z(80),Y1),        (Z(81),Y2),      PH2 0630
     1(Z(82),CABLN),    (Z(83),VISC),      (Z(84),T),         (Z(85),GMAX),    PH2 0640
     2(Z(86),WSGD),     (Z(87),WSGX),      (Z(88),GMADR),     (Z(89),GMAXR),   PH2 0650
     3(Z(90),S1),       (Z(91),S2),        (Z(92),S3),        (Z(93),S4),      PH2 0660
     4(Z(94),S5),       (Z(95),S6),        (Z(96),S7),        (Z(97),S8),      PH2 0670
     5(Z(98),S9),       (Z(99),S10)                                            PH2 0680
      EQUIVALENCE(Z(127),SS1),(Z(128),SS2),(Z(129),SS3),(Z(130),SS4),
     1(Z(131),SS5),(Z(132),SS6),(Z(133),SS7),(Z(134),SS8),(Z(135),SS9),
     2(Z(136),SS10),(Z(137),SS11)
      EQUIVALENCE(Z(140),SNR),(Z(141),STR),(Z(142),SNT),
     1(Z(143),STT),(Z(144),SNB),(Z(145),STB)
C                                                                              PH2 0690
     OEQUIVALENCE       (XX(2),X(1)),      (UR,UL,FLEFT),     (UR(100),YAMC),PH2 0700
     1(PR(100),SIGC),(PR,PL,GAMC),(UR,TAB),                                    PH2 0710
     2(UR(16),AMK),     (UR(31),PK),       (UR(46),QK),       (YY(2),Y(1))     PH2 0720
      EQUIVALENCE(AM,ASN),(AM(53),AST),(XL,ASNB),
     1(XL(53),ASTB),(YL,RSN),(YL(53),RST),(IW1,SIG33),
     2(IW1(53),DUDOT),(IW2,DVDOT),(IW2(53),DAIX)
      EQUIVALENCE(L,KL),(M,KAR),(MA,KA),(MB,KAL),
     1(MC,KBR),(MD,KB),(ME,KBL)
      EQUIVALENCE (Z(105),SNL),(Z(106),STL)
C                                                                              PH2 0730
C                                                                              PH2 0740
C                                                                              PH2 0760
C                                                                              MAIN0020
C     ****** NOTE 1 MATERIAL ONLY (X)) ************                            MAIN0030
C                                                                              MAIN0050
C     INPUT READS OIL DUMP TAPE OR
C     WILL CALL SUBROUTINE SET'UP WHICH
C     WILL MAKE A DUMP TAPE FOR CERTAIN TYPES OF PROBLEM
C     (SEE SECTION ON SET'UP)
C     ALSO CALCULATES DX AND DY AND EQUATION OF STATE DATA .....
      CALL INPUT                                                               MAIN0060
C     CDT ROUTINE CALCULATES DT(HYDRO TIME STEP)
C     AND PRESSURES, ADVANCE CYCLE NO. ETC.
   10 CALL CDT                                                                 MAIN0070
C     IN EDIT, DETERMINE WHETHER TO EXECUTE A LONG
C     PRINT, A SHORT PRINT, A TAPE DUMP, ETC. AND
C     CALCULATE TOTAL ENERGY IN SYSTEM(COMPARE
C     WITH ETH) TOTAL MASS, INTEGRATE TOTAL
C     COMPONENTS OF MOMENTA.
      CALL EDIT                                                                MAIN0080
      CALL SLITET(1,KOOOFX)                                                    MAIN0090
C      SENSE LITE 1 SIGNIFIES THIS
```

```
C       IS THE LAST CYCLE OF THIS RUN $$$$$$$$$$$$$$$
C       LITE TURNED ON IN THE EDIT ROUTINE ******
         GO TO(30,20),K000FX
C       PH1, INTEGRATE THE MOMENTA EQS. INTEGRATE
C       ENERGY EQUATION(ONLY CHANGES DUE TO WORK
C        TERMS). NO MOVEMENT OF MASS HERE
    20 CALL PH1
C        ****** PH3 CALCULATES THE CHANGE IN THE VELOCITY
C       COMPONENTS AND INTERNAL ENERGY DUE TO THE
C        STRESSES ACTING ON THE CELL ...
       CALL PH3
C       TRANSPORT MASS ACROSS BOUNDARIES (SOLVE
C       MASS TRANSPORT EQ.) TRANSPORT TERMS IN
C       THE MOMENTA AND ENERGY EQS. LEFT OUT OF
C       PH1, HERE APROXIMATED BY MASS MOVEMENT. CONSERVE
C       MASS, MOMENTA AND TOTAL ENERGY.
       CALL PH2
C
C
       GO TO 10
    30 CALL EXIT
       END
```

```
$IBFTC CARDS   LIST,DECK,REF
      SUBROUTINE CARDS
      DIMENSION TABLE(1),CARD(7),LABLE(1)
      COMMON          TABLE
C     A 2 IN COLUMN 1, ROUTINE WILL FIX THE
C     FLOATING PT. NO.
C     A 1 IN COLUMN 1, MEANS THIS IS LAST CARD TO
C     READ IN.
      EQUIVALENCE(TABLE(1),LABLE(1))
      WRITE (6,10)
    1 READ  (5,11)IEND,LOC,NUMWPC,(CARD(I),I=1,NUMWPC)
      WRITE (6,12)IEND,LOC,NUMWPC,(CARD(I),I=1,NUMWPC)
      DO 4 I=1,NUMWPC
      J=LOC+I-1
      IF(IEND-2)2,5,2
    5 LABLE(J)=IFIX(CARD(I))
      GO TO 4
    2 TABLE(J)=CARD(I)
    4 CONTINUE
      IF(IEND-1)1,3,1
    3 RETURN
C                FORMATS
   10 FORMAT(20H1   RFM   INPUT CARDS///)
   11 FORMAT(I1,I5,I1,0P7E9.4)
   12 FORMAT(1H I4,I7,I3,1P7E14.6)
      END
```

```
$IBFTC SETUP   LIST,DECK,REF
      SUBROUTINE SETUP
C     WILL ONLY GENERATE (1) MATERIAL.
C     PACKAGES MUST BE RECTANGLES.
C     ASSUMPTION OF = DX AND = DY
C     LOAD PK(4)=1.
      M=PK(4)
C     LOAD PK(5)=RIGHT BOUNDARY OF PELLET(I).
      MA=PK(5)
C     LOAD PK(6)=BOTTOM(J)+1 OF PELLET.
      MB=PK(6)
C     LOAD PK(7)=TOP(J) OF PELLET.
      MC=PK(7)
C     LOAD PK(8)=1.
      MD=PK(8)
C     LOAD PK(9)=RIGHT(I)BOUNDARY OF TARGET.
      ME=PK(9)
C     LOAD PK(10)=BOTTOM(J)+1 OF TARGET.
      MZ=PK(10)
C     LOAD PK(11)=TOP(J)OF TARGET.
      N=PK(11)
C     LOAD INITIAL DENSITY INTO Z(111).
      RHO=Z(111)
C     LOAD INITIAL PELLET VELOCITY INTO Z(112).
      VTEF=Z(112)
      KMAX=IMAX*JMAX+1
      KMAXA=KMAX+1
      JMAXA=JMAX+1
      IMAXA=IMAX+1
C     CLEAR ALL CELL ARRAYS.
      DO 1 K=1,KMAX
      U(K)=0.0
      V(K)=0.0
      P(K)=0.0
      AMX(K)=0.0
      AIX(K)=0.0
    1 CONTINUE
      DX(1)=DX(1)
      X(1)=DX(1)
      WS=X(1)**2
      IF(GAM)4,2,4
    4 PIDY=1.
      TAU(1)=DX(1)
      GO TO 3
    2 PIDY=3.1415927
      TAU(1)=WS*PIDY
C     CALCULATE DX,X,TAU
    3 DO 10 I=2,IMAX
      X(I)=X(I-1)+DX(1)
      DX(I)=DX(1)
```

```
      WSA=X(I)**2
      IF(GAM)5,6,5
    5 TAU(I)=DX(I)
      GO TO 10
    6 TAU(I)=PIDY*(WSA-WS)
      WS=WSA
   10 CONTINUE
      Y(1)=DY(1)
C     CALCULATE DY AND Y.
      DO 20 J=2,JMAX
      Y(J)=Y(J-1)+DY(1)
      DY(J)=DY(1)
   20 CONTINUE
      ETH=0.0
      DO 30 I=M,MA
      K=(MB-1)*IMAX+I+1
C     CALCULATE MASS, AND VELOCITY OF PELLET.
      DO 40 J=MB,MC
      AMX(K)=RHO*DY(J)*TAU(I)
      V(K)=VTEF
C     CALCULATE TOTAL ENERGY (ETH.)
      ETH=ETH+AMX(K)*(V(K)**2)/2.0
   40 K=K+IMAX
   30 CONTINUE
C     CALCULATE MASS OF TARGET.
      DO 50 I=MD,ME
      K=(MZ-1)*IMAX+I+1
      DO 60 J=MZ,N
      AMX(K)=RHO*DY(J)*TAU(I)
   60 K=K+IMAX
   50 CONTINUE
      IMAX=IMAX
      JMAX=JMAX
      SHELL=2.0
      CYCLE=0.0
      DT=0.0
      NMAX=0
      N1=2
      N2=3
      N3=0
      N4=127
      XMAX=X(IMAX)
      TXMAX=XMAX*2.0
      YMAX=Y(JMAX)
      TYMAX=YMAX*2.0
      REWIND 7
      WS=555.0
C     WRITE OUTPUT FOR OIL ON TAPE.
      WRITE ( 7)WS,CYCLE,N3
      WRITE ( 7)(Z(I),I=1,150)
```

```
      WRITE ( 7)(U(I),V(I),AMX(I),AIX(I),P(I),I=1,KMAXA)
      WRITE ( 7)X(0),(X(I),TAU(I),I=1,IMAX)
      WRITE ( 7)(Y(I),I=0,JMAX)
      WS=666.0
      WRITE ( 7)WS,WS,WS
      REWIND  7
      RETURN
      END
```

```
$IBFTC INPUT   LIST,DECK,REF
      SUBROUTINE INPUT                                                  INPU0010
C                                                                       INPU0760
C                                                                       INPU0900
C     TURN ON  SENSE  LITE  3.
      CALL SLITE (3)                                                    INPU0980
C                                                                       INPU0990
C     READ HEADER CARD (COLUMNS 2-72).
      READ  (5,8004)IWS                                                 INPU1000
      WRITE (6,8004)IWS                                                 INPU1010
C     CALL DATA.
    6 CALL CARDS                                                        INPU1020
C     IF PK(3) = OR GREATER THAN ZERO, CALL ROUTINE
C     SET-UP, OTHERWISE, BINARY OIL TAPE HAS BEEN MADE.
C     READ IN DATA FROM OIL DUMP TAPE, OR
C     GENERATE A DUMP TAPE FOR OIL, AND
C     CALCULATE DX AND DY FROM THE X AND
C     Y VALUES FROM TAPE.
      IF(PK(3))8887,8888,8888                                           INPU1030
 8888 CALL CARDS                                                        INPU1040
      CALL SETUP                                                        INPU1050
 8887 CONTINUE                                                          INPU1060
C                                                                       INPU1070
C                    READ TAPE                                          INPU1080
C     GO READ BINARY TAPE.
      GO TO 1000                                                        INPU1090
C                                                                       INPU1100
C                    READ IN REMAINING INPUT CARDS                      INPU1110
   10 CONTINUE                                                          INPU1120
      CALL CARDS                                                        INPU1130
      GO TO 2000                                                        INPU1140
C                                                                       INPU1150
C     SET THE PRESSURES TO ZERO.
   40 DO 45 K=1,KMAXA                                                   INPU1160
   45 P(K)=0.0                                                          INPU1170
C     INTEGRATE BACKWARDS ON CYCLE, TIME AND NO. OF
C     CYCLES BETWEEN ENERGY CHECK, SINCE THESE
C     ARE ADVANCED IN CDT.
C     NOTE, RSTOP = ENERGY FACTOR AND
C     SHELL = FACTOR ON SPEED OF SOUND CALC.
C     CONVERT FROM JERKS TO ERGS.
      Z(117)=Z(117)*RSTOP
      Z(119)=Z(119)*RSTOP
      Z(122)=Z(122)*RSTOP
      Z(126)=Z(126)*RSTOP
      Z(110)=Z(110)*RSTOP
      RSTOP=1.0                                                         INPU1178
      T=T-DTNA                                                          INPU1180
      NC=NC-1                                                           INPU1190
      IF(Z(149))3000,3001,3000
```

```
 3000 Z(148)=SQRT(Z(119)/Z(115))
      Z(149)=Z(149)*SHELL
      SHELL=1.0
 3001 CYCLE=NC
      NPC=NPC-1
      UVMAX=0.0
C     CALCULATE THE DX'S, SINCE THESE ARE NOT ON
C     TAPE.
      DO 50 I=1,IMAX
   50 DX(I)=X(I)-X(I-1)
C     CALCULATE THE DY'S, SINCE THESE ARE NOT ON
C     TAPE.
      DO 55 J=1,JMAX
   55 DY(J)=Y(J)-Y(J-1)
      J=MZ-8
C     PRINT Z BLOCK.
   62 DO 80 I=1,J,8
      K=I+7
      DO 65 J=I,K
      IF(Z(J))70,65,70
   65 CONTINUE
      GO TO 80
   70 K=I+7
      WRITE (6,8111)I,(Z(L),L=I,K)
   80 CONTINUE
C
C     ASSUMPTION THAT ALL DX AND DY ARE =
C     NOTE, DVK=K(0)/(RHO(0)*DX SQ.)
      WS=DX(1)*DX(1)
      DVK=DDXN/(Z(111)*WS)
C
      GO TO 10000
C
C
C
C     READ BINARY TAPE.
 1000 MZ=150
      IWS=0
 1003 REWIND 7
 1004 READ(7)PR(1),PR(2),N3
      NR=N3+5
 1006 IF(PR(1)-555.0)1010,1016,1010
 1010 IWS=IWS+1
 1011 IF(MOD(IWS,3))9902,9902,1003
 1016 IF(PR(2))1010,1018,1018
C     CHECK HERE FOR THE CORRECT CYCLE NUMBER.
 1018 IF(PK(2)-PR(2))1023,1023,1020
C     SKIP OVER, LOOK AT NEXT CYCLE.
 1020 DO 1022 L=2,NR
 1022 READ(7)
```

```
      GO TO 1004                                                        INPU1530
 1023 READ(7)(Z(I),I=1,MZ)
C     CHECK FOR THE CORRECT PROBLEM NO.
      IF(ABS(PROB-PK(1))-.01)1024,1024,9901                             INPU1550
 1024 READ(7)(U(I),V(I),AMX(I),AIX(I),P(I),I=1,KMAXA)
      READ(7)X(0),(X(I),TAU(I),I=1,IMAX)
      READ(7)(Y(I),I=0,JMAX)
 1025 CONTINUE                                                          INPU1650
 1034 READ(7)PR(1),PR(2),PR(3)
 1036 IF(PR(1)-555.0)9904,1040,1038                                     INPU1680
 1038 IF(PR(2)-666.0)9905,1040,9905                                     INPU1690
 1040 GO TO 10                                                          INPU1700
C**** END OF READ TAPE **************************************************INPU1710
C                                                                       INPU1720
C                                                                       INPU1730
C     CALCULATE MAX. GAMMA AND GAMMA/(GAMMA-1.).
C                                                                       INPU1740
 2000 IF(WSGX)9906,2010,2005                                            INPU1750
 2005 GAMX=1.0/(WSGX-1.0)                                               INPU1760
 2010 WSGX=(GAMX+1.0)/GAMX                                              INPU1770
      GMAXR=GAMX*WSGX                                                   INPU1780
 2012 IF(WSGD)9907,2020,2015                                            INPU1790
 2015 GAMD=1.0/(WSGD-1.0)                                               INPU1800
 2020 WSGD=(GAMD+1.0)/GAMD                                              INPU1810
      GMADR=GAMD*WSGD                                                   INPU1820
      GMAX=WSGD                                                         INPU1830
      IF(WSGD-WSGX)2025,2030,2030                                       INPU1840
 2025 GMAX=WSGX                                                         INPU1850
 2030 GO TO 40                                                          INPU1860
C**** END OF R E S *****************************************************INPU1870
C                                                                       INPU1880
C                                                                       INPU1890
C                     ERROR                                             INPU1900
 9901 NK=1023                                                           INPU1910
      GO TO 9999                                                        INPU1920
 9902 NK=1011                                                           INPU1930
      GO TO 9999                                                        INPU1940
 9904 NK=1036                                                           INPU1950
      GO TO 9999                                                        INPU1960
 9905 NK=1038                                                           INPU1970
      GO TO 9999                                                        INPU1980
 9906 NK=2000                                                           INPU1990
      GO TO 9999                                                        INPU2000
 9907 NK=2012                                                           INPU2010
 9999 NR=1                                                              INPU2020
      CALL DUMP                                                         INPU2030
C                                                                       INPU2040
10000 RETURN                                                            INPU2050
C                                                                       INPU2060
C                     FORMATS                                           INPU2070
```

```
 8000 FORMAT(7E10.3,I2)                                                  INPU20
 80040FORMAT(I1,71H                                                      INPU20
     1                                     )                             INPU21
 8111 FORMAT(I4,80I4)                                                    INPU21
C                                                                        INPU21
      END                                                                INPU21
```

```
$IBFTC CDT     LIST,DECK,REF
       SUBROUTINE CDT                                                   CDT 0010
C                                                                       CDT 0020
C                                                                       CDT 0990
C      ============================================                     CDT 1000
C                                                                       CDT 1010
C                                                                       CDT 1020
C      CHECK COURANT CONDITION AND PARTICLE
C      VELOCITY.
C      RECORD I AND J OF ZONE WHERE DT IS BEING
C      CONTROLLED.
 3000 VEL=0.0                                                           CDT 1030
 3005 DO 3050 I=1,I1                                                    CDT 1040
 3010 K=I+1                                                             CDT 1050
 3015 DO 3050 J=1,I2                                                    CDT 1060
      I=I                                                               CDT 1070
      J=J                                                               CDT 1080
 3020 IF(AMX(K))9901,3050,3025                                          CDT 1090
C                                                                       CDT 1100
C      CALCULATE PRESSURES FROM EQUATION OF STATE(ES).
 3025 CALL ES                                                           CDT 1110
C                                                                       CDT 1120
 3030 IF(ABS(P(K))-1.0E-20)3035,3035,3040                               CDT 1130
 3035 P(K)=0.0                                                          CDT 1140
 3040 IF(WSGX-VEL)3050,3050,3045                                        CDT 1150
 3045 VEL=WSGX                                                          CDT 1160
 3050 K=K+IMAX                                                          CDT 1170
 3055 KDT=1                                                             CDT 1180
      UVMAX=-1.0                                                        CDT 1190
 3070 DO 3255 I=1,I1                                                    CDT 1200
 3075 K=I+1                                                             CDT 1210
 3095 DO 3255 J=1,I2                                                    CDT 1220
 3100 KP=K+IMAX                                                         CDT 1230
      IF(AMX(K))9901,3255,4                                             CDT 1240
C      IF RHO(K) IS LESS THAN Z(138), CELL K
C      WILL BE BYPASSED FOR STABILITY CHECK.
    4 IF(AMX(K)/(TAU(I)*DY(J))-Z(138))3255,3255,3115                    CDT 1250
 3115 SIG=DX(I)                                                         CDT 1260
 3120 IF (DY(J)-SIG)3125,3130,3130                                      CDT 1270
 3125 SIG=DY(J)                                                         CDT 1280
C      C=SPEED OF SOUND FOR POLYTROPIC GAS AS
C      THE SQ. ROOT OF (GAMMA*P/RHO).
C      HERE CALCULATE THE SPEED OF SOUND FOR
C      THE EQUATION OF STATE
C      AS THE SQ. ROOT OF DP/DRHO.
 3130 IF(Z(148))4000,4000,4001                                          CDT 1290
 4000 WS=SQRT(GMAX*TAU(I)*DY(J)*ABS(P(K))/(AMX(K)))                     CDT 1300
      GO TO 3205                                                        CDT 1310
 4001 WSA=ABS(P(K))
      WS=Z(148)+Z(149)*(WSA**Z(150))                                    CDT 1330
```

```
 3205 WS=WS/SIG                                                       CDT 1350
 3210 IF(UVMAX-WS)3215,3220,3220                                      CDT 1360
 3215 N10=I                                                           CDT 1370
      N11=J                                                           CDT 1380
      UVMAX=WS                                                        CDT 1390
 3220 CONTINUE
C     EULERIAN CHECK FOR RADIAL PARTICLE VELOCITY.
    1 IF(GAM)2,3,2
    3 WS=ABS(U(K))/TAU(I)*X(I)/.5*PIDY                                CDT 1420
      GO TO 3225                                                      CDT 1430
C     FOR CARTESIAN CODE
    2 WS=ABS(U(K))/DX(I)                                              CDT 1440
 3225 IF(UVMAX-WS)3230,3235,3235                                      CDT 1450
 3230 UVMAX=WS                                                        CDT 1460
      N10=I                                                           CDT 1470
      N11=J                                                           CDT 1480
 3235 WS=ABS(V(K))/DY(J)                                              CDT 1490
 3240 IF(UVMAX-WS)3245,3250,3250                                      CDT 1500
 3245 N10=I                                                           CDT 1510
      N11=J                                                           CDT 1520
      UVMAX=WS                                                        CDT 1530
 3250 CONTINUE                                                        CDT 1540
 3255 K=K+IMAX                                                        CDT 1550
      IF(UVMAX)9912,9912,3260
C     FOR OPTIONS ON CABLN, CHECK
C     SECTION 3.4 IN GAMD-5580.
 3260 IF(CABLN)90,91,3300                                             CDT 1560
   90 DT=.5/VEL/UVMAX*Z(139)                                          CDT 1570
      GO TO 3295                                                      CDT 1580
   91 WS=UVMAX*DT                                                     CDT 1590
      WSA=0.5/VEL                                                     CDT 1600
 3265 IF(FFA-WSA)3276,3276,3270                                       CDT 1610
 3270 FFA=WSA                                                         CDT 1620
 3276 IF(WS-FFA)3285,3300,3280                                        CDT 1630
 3280 DT=DT/WS*FFB/0.9                                                CDT 1640
      GO TO 3295                                                      CDT 1650
 3285 IF(WS-FFB)3290,3290,3300                                        CDT 1660
 3290 DT=DT*FFA/WS*0.9                                                CDT 1670
 3295 KDT=0                                                           CDT 1680
C     INTEGRATE THE TIME AND CYCLE COUNTER.
 3300 T=T+DTNA                                                        CDT 1690
   85 IF(DTRAD)9911,80,81                                             CDT 1700
   80 NR=NRM                                                          CDT 1710
   84 WS=NR                                                           CDT 1720
      TRAD=DT/WS                                                      CDT 1730
      GO TO 82                                                        CDT 1740
   81 IWS=DT/DTRAD                                                    CDT 1750
      NR=IWS+1                                                        CDT 1760
   83 IF(NR-NRM)84,84,80                                              CDT 1770
   82 NC=NC+1                                                         CDT 1780
```

```
      CYCLE=NC                                                          CDT 1790
      NPC=NPC+1                                                         CDT 1800
 3305 IF(T)9909,3320,3310                                               CDT 1810
 3310 IF(KDT)9910,3315,3320                                             CDT 1820
 3315 WRITE (6,8000)T,DTNA,DT                                           CDT 1830
 3320 DTNA=DT                                                           CDT 1840
      GO TO 3325                                                        CDT 1850
C                    NEGATIVE MASS                                      CDT 1860
 9901 NK=3020                                                           CDT 1870
      GO TO 9999                                                        CDT 1880
 9909 NK=3305                                                           CDT 1890
      GO TO 9999                                                        CDT 1900
 9910 NK=3310                                                           CDT 1910
      GO TO 9999                                                        CDT 1920
C     THE DT WILL BE 0. OR NEGATIVE ,STOP
 9912 NK=1
      GO TO 9999
 9911 NK=85                                                             CDT 1930
 9999 NR=2                                                              CDT [illegible]
      CALL DUMP                                                         [illegible]
 3325 RETURN                                                            CDT 1960
80000FORMAT (17HOCHANGE DT ... T=1PE9.3,11H     DT(N)=1PE9.3,13H      DTCDT 1970
     1(N+1)=1PE9.3)                                                     CDT 1980
      END                                                               CDT 1990
```

```
$IBFTC PH1     LIST,DECK,REF
      SUBROUTINE PH1                                                    PH1 001
C                                                                       PH1 090
C     VELOCITIES, ENERGIES, PRESSURES ARE AT THE
C     CENTER OF THE CELL.
C     (2) PASSES THRU PH1 ARE REQUIRED. NO
C     MASS IS MOVED IN PH1.
C     ****** NOTE 1 MATERIAL ONLY (X)) ************                     PH1 098
C                                                                       PH1 099
C                                                                       PH1 100
C                                                                       PH1 101
C     ============================================                      PH1 102
C                                                                       PH1 103
C                                                                       PH1 104
      NRT=0                                                             PH1 105
      NRC=0                                                             PH1 106
      UU=1.E+15                                                         PH1 107
      UT=0.0                                                            PH1 108
C     YOU WILL GET BACK HERE IF AIX WAS LESS
C     THAN 0. AND PROVIDED SN=0.
 8000 VEL=1.0                                                           PH1 109
C     INITIALIZE MID-POINTS OF FIRST AND SECOND
C     CELL IN R DIRECTION.
      IF(GAM)9000,3301,9000
 9000 RC=1.
      RR=RC
      GO TO 3304
 3301 RC=DX(1)/2.0                                                      PH1 110
      RR=(X(1)+X(2))/2.0                                                PH1 111
 3304 K=2                                                               PH1 112
C     AXIS OF SYMMETRY BOUNDARY CONDITIONS.
      DO 3302 J=1,JMAX                                                  PH1 113
      PL(J)=P(K)                                                        PH1 114
      UL(J)=0.0                                                         PH1 115
 3302 K=K+IMAX                                                          PH1 116
C     FIRST PASS THRU, CALCULATE U AND V AT
C     CYCLE N+1, AND THE WORK TERMS USING U AND V
C     FROM CYCLE N.
C     SECOND PASS THRU, CALCULATE ONLY THE
C     CONTRIBUTION TO THE CHANGE IN INTERNAL ENERGY
C     FROM WORK TERMS EVALUATED FROM U AND V
C     AT CYCLE N+1.
      DO 3360 I=1,I1                                                    PH1 117
      K=I+1                                                             PH1 118
      IF(CVIS)7002,7003,7003                                            PH1 119
C     BOTTOM BOUNDARY IS TRANSMITTIVE.
 7002 VBLO=V(K)                                                         PH1 120
      PBLO=0.0                                                          PH1 121
      GO TO 7004                                                        PH1 122
C     BOTTOM BOUNDARY IS REFLECTIVE.
```

```
 7003 VBLO=0.0                                                          PH1 1230
      PBLO=P(K)                                                         PH1 1240
 7004 TAUDTS=TAU(I)*DT                                                  PH1 1250
C     I1= MAX.(I) OF DISTURBANCE IN R DIRECTION.
C     I2= MAX(J) OF DISTURBANCE IN Z DIRECTION.
C     DO LOOP IN J DIRECTION
      DO 3348 J=1,I2                                                    PH1 1260
      PIDTS=1.0/(PIDY*DT*DY(J))                                         PH1 1270
      IF(GAM)9002,9004,9002
 9002 PIDTS=2.*PIDTS
C     K= INDEX OF CELL IN QUESTION.
C     N= INDEX OF CELL ABOVE.
 9004 N=K+IMAX
 3305 IF(AMX(K))9902,3340,3306                                          PH1 1290
 3306 IF(IMAX-I)9903,3311,3310                                          PH1 1300
 3310 IF(AMX(K+1))9904,3312,3314                                        PH1 1310
C     WE ARE AT THE RIGHT BOUNDARY, SET PRESSURE
C     GRADIENT TO 0. IN R DIRECTION, MODIFY ETH.
C     FOR RIGHT BOUNDARY BEING TRANSMITTIVE.
 3311 PRR=PL(J)                                                         PH1 1320
 3307 ETH=ETH-PRR*U(K)/PIDTS*RC                                         PH1 1330
      GO TO 3313                                                        PH1 1340
C     RIGHT BOUNDARY CONDITION FOR THE MOMENTUM EQ.
C     ADJACENT TO EMPTY CELL.
 3312 PRR=0.0                                                           PH1 1350
 3313 URR=RC*U(K)                                                       PH1 1360
      GO TO 3316                                                        PH1 1370
C     CALCULATE PRESSURE AT INTERFACE(I) AND
C     (RU) FOR WORK TERM.
 3314 PRR=(P(K)+P(K+1))/2.0                                             PH1 1380
 3315 URR=(U(K)*RC+U(K+1)*RR)/2.0                                       PH1 1390
 3316 IF(JMAX-J)9905,3318,3320                                          PH1 1400
C     SET PRESSURE GRADIENT TO 0. THIS IS FOR TOP
C     BOUNDARY BEING TRANSMITTIVE.
 3318 PABOVE=PBLO                                                       PH1 1410
C     MODIFY ETH FOR TOP BOUNDARY CONDITION.
 3319 ETH=ETH-PABOVE*V(K)/2.0*TAUDTS                                    PH1 1420
      GO TO 3323                                                        PH1 1430
 3320 IF(AMX(N))9906,3322,3324                                          PH1 1440
C     TOP BOUNDARY CONDITION (EMPTY CELL ABOVE.)
C     TOP BOUNDARY CONDITION FOR VELOCITY (EMPTY CELL ABOVE).
 3322 PABOVE=0.0                                                        PH1 1450
 3323 VABOVE=V(K)                                                       PH1 1460
      GO TO 3328                                                        PH1 1470
C     CALCULATE PRESSURE AT INTERFACE(J)
 3324 PABOVE=(P(K)+P(N))/2.0                                            PH1 1480
      IF(CVIS)7001,3325,3325                                            PH1 1490
 7001 IF(1-J)3325,7000,9905                                             PH1 1500
C     BOTTOM BOUNDARY IS TRANSMITTIVE, SET PRESSURE
C     GRADIENT TO 0.
```

```
C       AND MODIFY ETH.
 7000 PBLO=PABOVE
      ETH=ETH+PBLO*V(K)/2.0*TAUDTS
C       VELOCITY AT INTERFACE(J)
 3325 VABOVE=(V(K)+V(N))/2.0
 3328 IF(VEL)9907,3404,3400
C       COMPUTE DELTA U AND DELTA V.
 3400 V(K)=V(K)+(PBLO-PABOVE)*TAUDTS/(AMX(K))
C        **** NOTE, EPSILON IS FOR C.G.S. UNITS *************
C       *** FOR OIL UNITS SET IT TO 1.E-8 *******
      IF(ABS(V(K))-1.)3401,3401,3402
 3401 V(K)=0.0
 3402 U(K)=U(K)+(PL(J)-PRR)/(AMX(K))*RC/PIDTS*2.0
      IF(ABS(U(K))-1.)3403,3403,3404
 3403 U(K)=0.0
C       CHECK FOR ADVANCING COUNTERS OF THE ACTIVE
C       GRID IN THE R DIRECTION.
 3404 IF(I-I1)6016,6005,6005
 6005 IF(U(K))6605,6606,6605
 6605 NRC=1
 6606 IF(V(K))6607,6004,6607
 6607 NRC=1
 6004 IF(AIX(K))6015,6016,6015
 6015 NRC=1
 6016 CONTINUE
C       HERE CALCULATE CHANGE IN INTERNAL ENERGY
C       DUE TO WORK TERMS ONLY.
      WS=(VBLO-VABOVE)*TAUDTS/2.0*P(K)
      RHO=WS+(UL(J)-URR)/PIDTS*P(K)
C       CONVERT TO SPECIFIC INTERNAL ENERGY.
 3332 WSX=AIX(K)+RHO/AMX(K)
      GO TO 1000
C       CHECK FOR NEGATIVE INTERNAL ENERGIES.
 1000 IF(WSX)1011,1001,1001
 1001 AIX(K)=WSX
      GO TO 3342
 1011 UT=1.0
C       COMPUTE NEW DT(STORE IN UU) ASSUMING
C       THAT DI/DT WILL BE THE SAME FOR A SMALLER
C       TIME STEP, THE NEW DT IS CHOSEN SUCH
C       THAT AIX(AT N+1)=2/3 OF AIX(N).
      WSA=2.0*AIX(K)/3.0*DT/(AIX(K)-WSX)
 1013 IF(WSA-UU)1014,1001,1001
 1014 UU=WSA
      GO TO 1001
C       CELL (K) IS EMPTY, SET INTERFACE QUANTITIES,
C       ASSUMING CELL TO THE RIGHT AND TOP ARE
C       NOT VOID.
 3340 PRR=0.0
      URR=U(K+1)*RR
```

```
      PABOVE=0.0                                                        PH1 1830
      VABOVE=V(N)                                                       PH1 1840
C     SET RIGHT QUANTITIES TO THE LEFT (FOR NEXT
C     COLUMN SWEEP) AND SET ABOVE QUANTITIES TO
C     BELOW FOR NEXT CELL ABOVE.
 3342 VBLO=VABOVE                                                       PH1 1850
      PL(J)=PRR                                                         PH1 1860
      UL(J)=URR                                                         PH1 1870
      K=N                                                               PH1 1880
 3348 PBLO=PABOVE                                                       PH1 1890
      LL=K-IMAX                                                         PH1 1900
C     CHECK FOR ADVANCING COUNTERS OF THE ACTIVE
C     GRID IN Z DIRECTION.
      IF(U(LL))6000,6001,6000                                           PH1 1910
 6000 NRT=1                                                             PH1 1920
 6001 IF(V(LL))6002,6003,6002                                           PH1 1930
 6002 NRT=1                                                             PH1 1940
 6003 IF(AIX(LL))6017,6018,6017                                         PH1 1950
 6017 NRT=1                                                             PH1 1960
 6018 CONTINUE                                                          PH1 1970
 3355 RC=RR                                                             PH1 1980
      IF(GAM)3360,9007,3360
 9007 RR=(X(I+1)+X(I+2))/2.0
 3360 CONTINUE                                                          PH1 2000
 3361 IF(VEL)9911,10000,3363                                            PH1 2010
 3363 VEL=0.0                                                           PH1 2020
      GO TO 3301                                                        PH1 2030
C                    ERROR                                              PH1 2040
 9902 NK=3305                                                           PH1 2050
      GO TO 9999                                                        PH1 2060
 9903 NK=3306                                                           PH1 2070
      GO TO 9999                                                        PH1 2080
 9904 NK=3310                                                           PH1 2090
      GO TO 9999                                                        PH1 2100
 9905 NK=3316                                                           PH1 2110
      GO TO 9999                                                        PH1 2120
 9906 NK=3320                                                           PH1 2130
      GO TO 9999                                                        PH1 2140
 9907 NK=3328                                                           PH1 2150
      GO TO 9999                                                        PH1 2160
 9911 NK=3361                                                           PH1 2170
 9999 NR=3                                                              PH1 2180
      CALL DUMP                                                         PH1 2190
C     IF SNINCT=0.) ANY NEGATIVE ENERGIES WILL
C     REMAIN. IF=0, CODE WILL TRY ANOTHER PASS
C     WITH A SMALLER DT.
10000 IF(SN)7030,7031,7030                                              PH1 2200
 7031 IF(UT)7020,7030,7010                                              PH1 2210
C     NEGATIVE ENERGIES HAVE OCCURED, INTEGRATE
C     BACK TO CYCLE N WITH (-DT).
```

```
 7010 UT=-1.0                                                          PH1 2220
      DT=-DT                                                           PH1 2230
C     YOU NOW HAVE INTEGRATED BACK TO CYCLE N. NOW
C     INTEGRATE TO CYCLE N+1 WITH NEW DT(STORED IN UU).
      GO TO 8000                                                       PH1 2240
 7020 UT=0.0                                                           PH1 2250
      DT=UU                                                            PH1 2260
      NR=DT/TRAD+1.0                                                   PH1 2270
      WS=NR                                                            PH1 2280
      TRAD=DT/WS                                                       PH1 2290
      DTNA=DT                                                          PH1 2300
      GO TO 8000                                                       PH1 2310
C     INCREASE ACTIVE GRID COUNTERS IF NEEDED.
 7030 I1=I1+NRC                                                        PH1 2320
      I2=I2+NRT                                                        PH1 2330
      IF(I1-IMAX)6100,6100,6200                                        PH1 2340
 6200 I1=IMAX                                                          PH1 2350
 6100 IF(I2-JMAX)6201,6201,6202                                        PH1 2360
 6202 I2=JMAX                                                          PH1 2370
 6201 RETURN                                                           PH1 2380
      END                                                              PH1 2390
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$IBFTC PH2     LIST,DECK,REF
      SUBROUTINE PH2                                                    PH2 0010
C     NOTE MIN. DENSITY FOR REZONE IS A INPUT NO. (VT))
C     Z(110)= CRITICAL ENERGY( BETWEEN GAS AND CONDENSED STATE)
C     Z(111)= INITIAL DENSITY
C     Z(112)= INITIAL VELOCITY OF PELLET
C     TOZONE = MINIMUM DENSITY FOR MASS FLOW
C                                                                       PH2 0900
C                                                                       PH2 0980
C     AMPY=MASS ACROSS TOP BOUNDARY OF CELL
C     AMUT=RADIAL MOMENTA OF THIS MASS
C     AMVT=AXIAL MOMENTA OF THIS MASS
C     DELET=TOTAL SPECIFIC ENERGY OF THIS MASS
C
C     AMMP=MASS ACROSS RIGHT BOUNDARY OF CELL
C     AMUR=RADIAL MOMENTA OF THIS MASS
C     AMVR=AXIAL MOMENTA OF THIS MASS
C     DELER=TOTAL SPECIFIC ENERGY OF THIS MASS
C
C     AMMY=MASS ACROSS BOTTOM BOUNDARY OF CELL
C     AMMU=RADIAL MOMENTA OF THIS MASS
C     AMMV=AXIAL MOMENTA OF THIS MASS
C     DELEB=TOTAL SPECIFIC ENERGY OF THIS MASS
C
C     GAMC=MASS ACROSS LEFT BOUNDARY OF CELL
C     FLEFT=RADIAL MOMENTA OF THIS MASS
C     YAMC=AXIAL MOMENTA OF THIS MASS
C     SIGC=TOTAL SPECIFIC ENERGY OF THIS MASS
C     ==========================================                        PH2 0990
C                                                                       PH2 1010
      NRT=0                                                             PH2 1020
      NRC=0                                                             PH2 1030
      REZ=0.0                                                           PH2 1040
      CALL SLITE (0)                                                    PH2 1050
      PIDTS=1.0/(PIDY*DT)                                               PH2 1060
  101 DO 103 J=1,JMAX                                                   PH2 1070
  102 GAMC(J)=0.0                                                       PH2 1080
      FLEFT(J)=0.0                                                      PH2 1090
      YAMC(J)=0.0                                                       PH2 1100
      SIGC(J)=0.0                                                       PH2 1110
  103 CONTINUE                                                          PH2 1120
  104 DO 547 I=1,I1                                                     PH2 1130
      J=1                                                               PH2 1140
  105 K=I+1                                                             PH2 1150
   80 IF(AMX(K))9900,97,81                                              PH2 1160
   81 IF(V(K))82,97,97                                                  PH2 1170
   97 AMMV=0.0                                                          PH2 1180
      GO TO 98                                                          PH2 1190
   82 AMMY=AMX(K)*V(K)*DT/DY(J)                                         PH2 1200
   83 IF(AMMY+AMX(K))84,85,85                                           PH2 1210
```

```
   84 AMMY=-AMX(K)                                                      PH2 1220
   85 IF(CVIS)106,99,99                                                 PH2 1230
C     BOTTOM BOUNDARY IS TRANSMITTIVE, MATERIAL IS MOVING
C     OUT, REMOVE ITS ENERGY FROM ETH.
  106 AMMU=AMMY*U(K)                                                    PH2 1240
      AMMV=AMMY*V(K)                                                    PH2 1250
      DELEB=AIX(K)+(U(K)**2+V(K)**2)/2.0                                PH2 1260
      WS=(U(K)**2+V(K)**2)/2.0                                          PH2 1270
      ETH=ETH+AMMY*(AIX(K)+WS)                                          PH2 1280
      GO TO 107                                                         PH2 1290
C     BOTTOM BOUNDARY IS REFLECTIVE, NET MOMENTA CHANGE
C     IN Z DIRECTION IS 2 MV.
   99 AMMV=2.0*AMMY*V(K)                                                PH2 1300
   98 AMMY=0.0                                                          PH2 1310
      AMMU=0.0                                                          PH2 1320
      DELEB=0.0                                                         PH2 1330
C     BEGIN DO LOOP IN J(Z) DIRECTION.
  107 DO 546 J=1,I2                                                     PH2 1340
  108 L=K+IMAX                                                          PH2 1350
      I=I                                                               PH2 1360
      J=J                                                               PH2 1370
      AREA=0.0                                                          PH2 1380
      VEL=0.0                                                           PH2 1390
      FS=0.0                                                            PH2 1400
  210 IF(JMAX-J)211,211,207                                             PH2 1410
  211 VEL=1.0                                                           PH2 1420
      GO TO 208                                                         PH2 1430
  207 IF(AMX(L))215,215,214                                             PH2 1440
  214 IF(AMX(K))216,216,209                                             PH2 1450
  216 VABOVE=V(L)                                                       PH2 1460
      GO TO 212                                                         PH2 1470
  215 IF(AMX(K))205,205,208                                             PH2 1480
  205 VABOVE=0.0                                                        PH2 1490
      GO TO 212                                                         PH2 1500
  208 VABOVE=V(K)                                                       PH2 1510
      GO TO 212                                                         PH2 1520
  209 VABOVE=(V(K)+V(L))/2.0                                            PH2 1530
  212 CONTINUE                                                          PH2 1540
      I=I                                                               PH2 1550
      J=J                                                               PH2 1560
      FS=0.0                                                            PH2 1570
  404 IF(IMAX-I)412,412,405                                             PH2 1580
  405 IF(AMX(K+1))411,411,409                                           PH2 1590
  409 IF(AMX(K))410,410,407                                             PH2 1600
  410 URR=U(K+1)                                                        PH2 1610
      GO TO 408                                                         PH2 1620
  411 IF(AMX(K))403,403,406                                             PH2 1630
  403 URR=0.0                                                           PH2 1640
      GO TO 408                                                         PH2 1650
C     WE ARE AT THE RIGHT BOUNDARY OF THE GRID, THE
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C       BOUNDARY CONDITION HERE IS TRANSMITTIVE.
  412 FS=1.0                                                    PH2 1660
  406 URR=U(K)                                                  PH2 1670
      GO TO 408                                                 PH2 1680
  407 URR=(U(K)+U(K+1))/2.0                                     PH2 1690
  408 CONTINUE                                                  PH2 1700
  109 IF(AREA)9901,301,547                                      PH2 1710
  301 IF(VABOVE)300,304,302                                     PH2 1720
  302 IF(AMX(K))9900,304,8800                                   PH2 1730
 8800 IF(J-1)9900,303,8801                                      PH2 1740
 8801 KP=K-IMAX                                                 PH2 1750
      IF(AMX(KP))9900,8803,303                                  PH2 1760
C       A CHECK HERE TO INSURE THAT THE BOTTOM ZONES
C       OF THE PROJECTILE EMPTY (FOR HYPERVELOCITY) UP UNTIL
 8803 IF(AIX(K)-Z(122))350,303,303
  350 IF(AMX(L))9900,303,306
  303 M=K                                                       PH2 1780
      JJ=J                                                      PH2 1790
      GO TO 307                                                 PH2 1800
  304 AMPY=0.0                                                  PH2 1810
  308 AMUT=0.0                                                  PH2 1820
      AMVT=0.0                                                  PH2 1830
      DELET=0.0                                                 PH2 1840
      GO TO 501                                                 PH2 1850
  300 IF(VEL)9901,305,304                                       PH2 1860
  305 IF(AMX(L))9903,304,306                                    PH2 1870
  306 M=L                                                       PH2 1880
      JJ=J+1                                                    PH2 1890
  307 IF(VEL)6130,6130,6140                                     PH2 1900
 6130 WSA=(V(K)+V(L))/2.0                                       PH2 1910
      WSB=1.0+(V(L)-V(K))/(DY(JJ)*SBOUND)*DT                    PH2 1920
      VABOVE=WSA/WSB                                            PH2 1930
C       CALCULATE THE MASS FLUX AT THE TOP OF CELL K.
 6140 AMPY=AMX(M)*VABOVE/DY(JJ)*DT                              PH2 1940
  501 IF(URR)500,504,502                                        PH2 1950
  502 IF(AMX(K))9900,504,503                                    PH2 1960
  503 IF(I-1)7001,7001,7002
 7001 M=K
      N=I                                                       PH2 1980
      GO TO 508                                                 PH2 1990
 7002 KP=K-1
      IF(AMX(KP))9900,7003,7001
 7003 IF(AIX(K)-Z(122))357,7001,7001
  357 IF(I-IMAX)351,7001,7001
  351 IF(AMX(K+1))9900,7001,507
  504 AMMP=0.0                                                  PH2 2000
      AMUR=0.0                                                  PH2 2010
      AMVR=0.0                                                  PH2 2020
      DELER=0.0                                                 PH2 2030
      GO TO 1                                                   PH2 2040
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  500 IF(FS)9905,506,504                                      PH2 2050
  506 IF(AMX(K+1))9904,504,507                                PH2 2060
  507 M=K+1                                                   PH2 2070
      N=I+1                                                   PH2 2080
  508 IF(FS)6100,6100,6110                                    PH2 2090
 6100 WSA=(U(K)+U(K+1))/2.0                                   PH2 2100
      WSB=1.0+(U(K+1)-U(K))/(DX(N)*SBOUND)*DT                 PH2 2110
      URR=WSA/WSB                                             PH2 2120
C     CALCULATE THE MASS FLUX AT THE RIGHT OF CELL K.
 6110 DEN=AMX(M)/TAU(N)                                       PH2 2130
      IF(GAM)9989,9990,9989
 9989 CART=1.
      GO TO 9991
 9990 CART=X(I)/.5
 9991 AMMP=DEN/PI[illegible]TS*CART*URR
    1 IF(AMMP)16,[illegible],8820                             PH2 2150
 8820 IF(GAMC(J))74,74,8821                                   PH2 2160
 8821 IF(FS)6120,6120,74                                      PH2 2170
 6120 IF(AMX(K+1))9903,8822,74                                PH2 2180
 8822 IF(AMX(K)/(TAU(I)*DY(J))-Z(111))8823,74,74              PH2 2190
 8823 IF(AIX(K)-Z(110))8824,74,74                             PH2 2200
 8824 WS=GAMC(J)+AMX(K)-TAU(I)*DY(J)*Z(111)                   PH2 2210
      IF(WS)8826,8826,8825                                    PH2 2220
 8825 AMMP=WS                                                 PH2 2230
      GO TO 74                                                PH2 2240
 8826 AMMP=0.0                                                PH2 2250
   74 JTAG=0                                                  PH2 2260
C     BEGIN CHECKING TO SEE IF THEIR IS ANY
C     PREFERENTIAL MASS FLUX BECAUSE OF CHOICE OF
C     INDEXING DIRECTION.
    2 IF(AMPY)3,4,4                                           PH2 2270
C     TOP FLUX IS INTO CELL K.
    3 ITAG=1                                                  PH2 2280
      WSB=AMPY                                                PH2 2290
      AMPY=0.0                                                PH2 2300
      GO TO 64                                                PH2 2310
    4 ITAG=0                                                  PH2 2320
   64 IF(AMMY)9,5,5                                           PH2 2330
C     BOTTOM FLUX IS INTO CELL K.
    5 IF(GAMC(J))7,6,6                                        PH2 2340
C     LEFT FLUX IS INTO CELLK.
    6 WS=AMX(K)                                               PH2 2350
      GO TO 11                                                PH2 2360
C     LEFT FLUX IS OUT.
    7 WS=AMX(K)+GAMC(J)                                       PH2 2370
      GO TO 11                                                PH2 2380
C     BOTTOM FLUX IS OUT OF CELL K.
    9 IF(GAMC(J))10,8,8                                       PH2 2390
C     LEFT FLUX IS INTO CELL K.
    8 WS=AMX(K)+AMMY                                          PH2 2400
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      GO TO 11                                                          PH2 2410
C     LEFT FLUX IS OUT OF CELL K.
   10 WS=AMX(K)+GAMC(J)+AMMY                                            PH2 2420
   11 WSA=AMPY+AMMP                                                     PH2 2430
   12 IF(WSA-WS)75,75,13                                                PH2 2440
C     CHANGE TOP AND RIGHT FLUX TO BE THE
C     OLD FLUX TIMES THE MASS OF THE CELL/THE SUM
C     OF THE OLD FLUXES.
   13 AMPY=AMPY*WS/WSA                                                  PH2 2450
      AMMP=AMMP*WS/WSA                                                  PH2 2460
   75 IF(JTAG)14,73,14                                                  PH2 2470
   73 WSC=AMMP                                                          PH2 2480
   14 IF(ITAG)15,7000,15                                                PH2 2490
   15 AMPY=WSB                                                          PH2 2500
      ITAG=0                                                            PH2 2510
C     GO CHECK CELL ABOVE.
      GO TO 40                                                          PH2 2520
C     RIGHT FLUX IS INTO CELL K.
   16 IF(FS)76,17,76                                                    PH2 2530
   76 WSC=AMMP                                                          PH2 2540
C     I=IMAX, SO CHECK CELL ABOVE K.
      GO TO 40                                                          PH2 2550
   17 IF(I+1-IMAX)19,18,9908                                            PH2 2560
   18 URRR=U(K+1)/2.0                                                   PH2 2570
      GO TO 20                                                          PH2 2580
   19 URRR=(U(K+1)+U(K+2))/2.0                                          PH2 2590
   20 IF(URRR)39,39,21                                                  PH2 2600
C     FLUX IS OUT OF THE RIGHT OF CELL(K+1).
   21 IF(GAM)9992,9993,9992
 9993 CART=X(I+1)*2.
      GO TO 9994
 9992 CART=1.
 9994 URRR=URRR/TAU(I+1)*AMX(K+1)/PIDTS*CART
   22 IF(J-1)9909,23,24                                                 PH2 2620
   23 VBLO=V(K+1)/2.0                                                   PH2 2630
      GO TO 26                                                          PH2 2640
   24 KP=K+1-IMAX                                                       PH2 2650
      VBLO=(V(K+1)+V(KP))/2.0                                           PH2 2660
   26 IF(VBLO)25,38,38                                                  PH2 2670
C     FLUX IS OUT OF THE BOTTOM OF CELL(K+1).
   25 VBLO=AMX(K+1)/DY(J)*VBLO*DT                                       PH2 2680
   27 IF(VEL)28,29,28                                                   PH2 2690
   28 VAB=V(K+1)/2.0                                                    PH2 2700
      GO TO 31                                                          PH2 2710
   29 KP=K+IMAX+1                                                       PH2 2720
      VAB=(V(K+1)+V(KP))/2.0                                            PH2 2730
   31 IF(VAB)36,36,30                                                   PH2 2740
C     FLUX IS OUT OF TOP.
   30 VAB=AMX(K+1)/DY(J)*VAB*DT                                         PH2 2750
   32 WS=AMX(K+1)                                                       PH2 2760
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   33 WSA=URRR-AMMP-VBLO+VAB                                                PH2 2770
   34 IF(WSA-WS)77,77,35                                                    PH2 2780
   35 AMMP=AMMP*WS/WSA                                                      PH2 2790
   77 JTAG=1                                                                PH2 2800
      WSC=AMMP                                                              PH2 2810
      AMMP=0.0                                                              PH2 2820
      GO TO 2                                                               PH2 2830
C     FLUX AT TOP IS INTO CELL (K+1).
   36 WS=AMX(K+1)                                                           PH2 2840
   37 WSA=URRR-AMMP-VBLO                                                    PH2 2850
      GO TO 34                                                              PH2 2860
C     FLUX IS IN FROM BOTTOM INTO CELL (K+1).
   38 VBLO=0.0                                                              PH2 2870
      GO TO 27                                                              PH2 2880
C     FLUX IS INTO CELL (K+1) FROM RIGHT.
   39 URRR=0.0                                                              PH2 2890
      GO TO 22                                                              PH2 2900
C     RIGHT FLUX OUT OF CELL (K) IS POSITIVE AND TOP
C     FLUX IS COMING INTO CELL (K) FROM (K+IMAX).
   40 IF(VEL)7000,41,7000                                                   PH2 2910
   41 IF(FS)42,43,42                                                        PH2 2920
C     WE ARE AT THE RIGHT BOUNDARY OF THE GRID.
   42 KP=K+IMAX                                                             PH2 2930
      URT=U(KP)/2.0                                                         PH2 2940
      GO TO 45                                                              PH2 2950
   43 KP=K+IMAX                                                             PH2 2960
      URT=(U(KP)+U(KP+1))/2.0                                               PH2 2970
   45 IF(URT)46,46,70                                                       PH2 2980
C     FLUX AT RIGHT (CELL M) IS NEGATIVE.
   46 URT=0.0                                                               PH2 2990
      GO TO 47                                                              PH2 3000
   70 KP=K+IMAX                                                             PH2 3010
      IF(GAM)9996,9997,9996
 9997 CART=X(I)*2.
      GO TO 9998
 9996 CART=1.
 9998 URT=URT/TAU(I)*AMX(KP)/PIDTS*CART
C     FLUX AT RIGHT (CELL M) IS POSITIVE.
   47 IF(J+1-JMAX)48,49,9910                                                PH2 3030
   48 KP=K+IMAX                                                             PH2 3040
      KLL=KP+IMAX
      VABT=(V(KP)+V(KLL))/2.
      GO TO 51                                                              PH2 3070
   49 KP=K+IMAX                                                             PH2 3080
      KLL=KP+IMAX
      VABT=V(KP)/2.0                                                        PH2 3100
   51 IF(VABT)8810,71,72                                                    PH2 3110
C     FLUX IS IN FROM TOP OF CELL M.
 8810 IF(AMX(K))9903,8811,71                                                PH2 3120
C     CHECK FOR SOLID OR VAPOR.
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 8811 IF(AMX(KP)/(TAU(I)*DY(J+1))-Z(111))8812,71,71                PH2 3130
 8812 IF(AIX(KP)-Z(110))8813,71,71                                 PH2 3140
 8813 VABT=VABT*AMX(KLL)/DY(J+2)*DT
 8814 WS=-VABT+AMX(KP)-TAU(I)*DY(J+1)*Z(111)                       PH2 3160
 8815 IF(WS)8817,8817,8816                                         PH2 3170
 8816 AMPY=-WS                                                     PH2 3180
      GO TO 71                                                     PH2 3190
 8817 AMPY=0.0                                                     PH2 3200
   71 VABT=0.0                                                     PH2 3210
      GO TO 60                                                     PH2 3220
   72 VABT=VABT*AMX(KP)/DY(J+1)*DT                                 PH2 3230
   52 IF(GAMC(J+1))54,53,53                                        PH2 3240
   53 WS=AMX(KP)                                                   PH2 3250
      GO TO 55                                                     PH2 3260
   54 WS=AMX(KP)+GAMC(J+1)                                         PH2 3270
   55 WSA=VABT-AMPY+URT                                            PH2 3280
      GO TO 57                                                     PH2 3290
   60 IF(GAMC(J+1))61,61,59                                        PH2 3300
   61 WS=AMX(KP)+GAMC(J+1)                                         PH2 3310
      GO TO 58                                                     PH2 3320
   59 WS=AMX(KP)                                                   PH2 3330
   58 WSA=-AMPY+URT                                                PH2 3340
   57 IF(WSA-WS)7000,7000,56                                       PH2 3350
   56 AMPY=AMPY*WS/WSA                                             PH2 3360
      GO TO 7000                                                   PH2 3370
 7000 AMMP=WSC                                                     PH2 3380
  309 IF(AMPY)8834,8831,8833                                       PH2 3390
 8833 IF(JMAX-J)9911,318,8835                                      PH2 3400
 8835 KP=K+IMAX                                                    PH2 3410
 8836 IF(AMX(KP))9900,8837,318                                     PH2 3420
C     **** NOTE *****************************************************
C     ACROSS FREE SURFACE, HOLD UP MASS FLUX
C      UNLESS THIS MASS PRODUCES A DENSITY GREATER THAN TOZONE.
C     ***************************************************************
 8837 IF(AMPY/(TAU(I)*DY(J))-TOZONE)8838,318,318                   PH2 3430
 8838 AMPY=0.0                                                     PH2 3440
      GO TO 8831                                                   PH2 3450
 8834 IF(J-1)9911,325,8839                                         PH2 3460
 8839 IF(AMX(K))9900,8840,325                                      PH2 3470
 8840 IF(-AMPY/(TAU(I)*DY(J+1))-TOZONE)8841,325,325                PH2 3480
 8841 AMPY=0.0                                                     PH2 3490
      GO TO 8831                                                   PH2 3500
  318 DELM=GAMC(J)+AMMY-AMPY                                       PH2 3510
  322 IF(VEL)9901,324,323                                          PH2 3520
  323 WS=U(K)**2+V(K)**2                                           PH2 3530
C     MATERIAL HAS LEFT THE TOP, TRIGGER REZONE
C     FLAG, REMOVE ITS ENERGY FROM ETH(TOTAL ENERGY OF SYSTEM).
      ETH=ETH-AMPY*(AIX(K)+WS/2.0)                                 PH2 3540
      IF(AMPY/(TAU(I)*DY(J))-VT)324,324,6900
 6900 REZ=1.0                                                      PH2 3560
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  324 AMUT=AMPY*U(K)                                                PH2 3570
      AMVT=AMPY*V(K)                                                PH2 3580
      GO TO 326                                                     PH2 3590
  325 CONTINUE                                                      PH2 3600
 8831 AMUT=AMPY*U(L)                                                PH2 3610
      AMVT=AMPY*V(L)                                                PH2 3620
      DELM=GAMC(J)-AMPY+AMMY                                        PH2 3630
  326 IF(AMPY)327,328,328                                           PH2 3640
  327 DELET=AIX(L)+(U(L)**2+V(L)**2)/2.0                            PH2 3650
      GO TO 333                                                     PH2 3660
  328 IF(AMMY)329,330,330                                           PH2 3670
  329 DELET=DELEB                                                   PH2 3680
      GO TO 333                                                     PH2 3690
  330 IF(GAMC(J))331,332,332                                        PH2 3700
  331 DELET=SIGC(J)                                                 PH2 3710
      GO TO 333                                                     PH2 3720
  332 DELET=AIX(K)+(U(K)**2+V(K)**2)/2.0                            PH2 3730
C      SUM UP RADIAL MOMENTA FOR ALL FLUXES EXCEPT
C      THE RIGHT AND STORE IN SIGMU.
  333 SIGMU=FLEFT(J)+AMMU-AMUT                                      PH2 3740
C      SUM UP AXIAL MOMENTA FOR ALL FLUXES EXCEPT THE
C      RIGHT AND STORE IN SIGMV.
      SIGMV=YAMC(J)+AMMV-AMVT                                       PH2 3750
C      SUM UP TOTAL ENERGY CARRIED BY THESE FLUXES
C      EXCEPT THE RIGHT FLUX AND STORE IN DELEK.
      DELEK=GAMC(J)*SIGC(J)+AMMY*DELEB-AMPY*DELET                   PH2 3760
  509 IF(AMMP)8843,518,8844                                         PH2 3770
 8844 IF(IMAX-I)9911,518,8845                                       PH2 3780
 8845 IF(AMX(K+1))9900,8846,518                                     PH2 3790
 8846 IF(AMMP/(TAU(I)*DY(J))-TOZONE)8847,518,518                    PH2 3800
 8847 AMMP=0.0                                                      PH2 3810
      GO TO 518                                                     PH2 3820
 8843 IF(I-1)9911,512,8848                                          PH2 3830
 8848 IF(AMX(K))9900,8849,512                                       PH2 3840
 8849 IF(-AMMP/(TAU(I+1)*DY(J))-TOZONE)8850,512,512                 PH2 3850
 8850 AMMP=0.0                                                      PH2 3860
      GO TO 518                                                     PH2 3870
  512 DELM=DELM-AMMP+AMX(K)                                         PH2 3880
  513 CONTINUE                                                      PH2 3890
  514 CONTINUE                                                      PH2 3900
 8828 AMUR=AMMP*U(K+1)                                              PH2 3910
      AMVR=AMMP*V(K+1)                                              PH2 3920
      GO TO 525                                                     PH2 3930
  518 DELM=DELM-AMMP+AMX(K)                                         PH2 3940
  521 CONTINUE                                                      PH2 3950
  522 IF(FS)9905,524,523                                            PH2 3960
  523 WS=U(K)**2+V(K)**2                                            PH2 3970
      ETH=ETH-AMMP*(AIX(K)+WS/2.0)                                  PH2 3980
      IF(AMMP/(TAU(I)*DY(J))-VT)524,524,6901
 6901 REZ=1.0                                                       PH2 4000
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  524 AMUR=AMMP*U(K)                                                 PH2 4010
      AMVR=AMMP*V(K)                                                 PH2 4020
  525 SIGMU=SIGMU-AMUR                                               PH2 4030
      SIGMV=SIGMV-AMVR                                               PH2 4040
  526 TIC=0.0                                                        PH2 4050
  527 IF(AMMP)528,529,529                                            PH2 4060
  528 DELER=AIX(K+1)+(U(K+1)**2+V(K+1)**2)/2.0                       PH2 4070
      GO TO 537                                                      PH2 4080
  529 IF(AMMY)530,531,531                                            PH2 4090
  530 DELER=DELEB                                                    PH2 4100
      GO TO 536                                                      PH2 4110
  531 IF(GAMC(J))532,533,533                                         PH2 4120
  532 DELER=SIGC(J)                                                  PH2 4130
      GO TO 536                                                      PH2 4140
  533 IF(AMPY)535,535,534                                            PH2 4150
  534 DELER=DELET                                                    PH2 4160
      GO TO 536                                                      PH2 4170
  535 DELER=AIX(K)+(U(K)**2+V(K)**2)/2.0                             PH2 4180
  536 TIC=1.0                                                        PH2 4190
  537 DELEK=DELEK-AMMP*DELER                                         PH2 4200
  538 IF(TIC)9907,539,550                                            PH2 4210
  550 WS=DELER                                                       PH2 4220
      GO TO 999                                                      PH2 4230
  539 WS=AIX(K)+(U(K)**2+V(K)**2)/2.0                                PH2 4240
  999 IF(DELM)998,543,540                                            PH2 4250
  998 IF(AMX(K)*1.E-6+DELM)9906,997,997                              PH2 4260
  997 DELM=0.0                                                       PH2 4270
      GO TO 543                                                      PH2 4280
C     ENK=TOTAL ENERGY OF CELL (K) + ENERGY THAT
C     HAS BEEN ADDED AND LOST.
  540 ENK=AMX(K)*WS+DELEK                                            PH2 4290
C     BY CONSERVING AXIAL MOMENTA, CALCULATE THE NEW
C     AXIAL VELOCITY COMPONENT FOR CELL K.
  541 U(K)=(SIGMU+AMX(K)*U(K))/DELM                                  PH2 4300
C     BY CONSERVING RADIAL MOMENTA, CALCULATE THE NEW
C     RADIAL VELOCITY COMPONENT FOR CELL K.
  601 V(K)=(SIGMV+AMX(K)*V(K))/DELM                                  PH2 4310
      IF(I-I1)603,6604,6604                                          PH2 4320
 6604 IF(U(K))6605,6606,6605                                         PH2 4330
 6605 NRC=1                                                          PH2 4340
 6606 IF(V(K))6607,6608,6607                                         PH2 4350
 6607 NRC=1                                                          PH2 4360
 6608 IF(AIX(K))6609,6610,6609                                       PH2 4370
 6609 NRC=1                                                          PH2 4380
 6610 CONTINUE                                                       PH2 4390
  603 WS=U(K)**2+V(K)**2                                             PH2 4400
C     BY CONSERVING BOTH TOTAL ENERGY AND
C     MOMENTA, CALCULATE THE NEW SPECIFIC
C     INTERNAL ENERGY FOR CELL K.
  542 AIX(K)=ENK/DELM-WS/2.0                                         PH2 4410
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  543 AMX(K)=DELM                                                   PH2 44
      IF(AMX(K))9900,2007,544                                       PH2 44
 2007 AIX(K)=0.0                                                    PH2 44
      U(K)=0.0                                                      PH2 44
      V(K)=0.0                                                      PH2 44
      P(K)=0.0                                                      PH2 44
C     THE RIGHT VALUES OF CELL (K) BECOME THE LEFT
C     VALUES OF CELL (K+1).
  544 GAMC(J)=AMMP                                                  PH2 44
      FLEFT(J)=AMUR                                                 PH2 44
      YAMC(J)=AMVR                                                  PH2 45
      SIGC(J)=DELER                                                 PH2 45
C     THE TOP VALUES OF CELL(K) BECOME THE
C     BOTTOM VALUES FOR CELL (K+IMAX).
  545 AMMY=AMPY                                                     PH2 45
      AMMU=AMUT                                                     PH2 45
      AMMV=AMVT                                                     PH2 45
      DELEB=DELET                                                   PH2 45
  546 K=K+IMAX                                                      PH2 45
      LL=K-IMAX                                                     PH2 45
      IF(U(LL))6500,6600,6500                                       PH2 45
 6500 NRT=1                                                         PH2 45
 6600 IF(V(LL))6601,6602,6601                                       PH2 46
 6601 NRT=1                                                         PH2 46
 6602 IF(AIX(L))6611,547,6611                                       PH2 46
 6611 NRT=1                                                         PH2 46
  547 CONTINUE                                                      PH2 46
      I1=I1+NRC                                                     PH2 46
      I2=I2+NRT                                                     PH2 46
      IF(IMAX-I1)6700,6701,6702                                     PH2 46
 6700 I1=IMAX                                                       PH2 46
 6701 CONTINUE                                                      PH2 46
 6702 IF(JMAX-I2)6800,6801,6802                                     PH2 47
 6800 I2=JMAX                                                       PH2 47
 6801 CONTINUE                                                      PH2 47
 6802 GO TO 548                                                     PH2 47
 9901 NK=300                                                        PH2 47
      GO TO 9999                                                    PH2 47
 9900 NK=302                                                        PH2 47
      GO TO 9999                                                    PH2 47
 9903 NK=305                                                        PH2 47
      GO TO 9999                                                    PH2 47
 9904 NK=506                                                        PH2 48
      GO TO 9999                                                    PH2 48
 9905 NK=500                                                        PH2 48
      GO TO 9999                                                    PH2 48
 9906 NK=513                                                        PH2 48
      GO TO 9999                                                    PH2 48
 9911 NK=8833                                                       PH2 48
      GO TO 9999                                                    PH2 48
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 9908 NK= 17
      GO TO 9999
 9909 NK= 22
      GO TO 9999
 9910 NK= 47
      GO TO 9999
 9907 NK=538
 9999 NK=4
      CALL DUMP
  548 SUM=0.0
 2005 DO 2001 I=1,I1
      K=I+1
      DO 2000 J=1,I2
      IF(AMX(K))2000,2000,2009
C     IF ANY RHO (CELL DENSITY) IS LESS THAN TOZONE,
C     SET THE MASS TO ZERO, AND TALLY THE
C     MOMENTAS AND ENERGIES IN THE Z STORAGE, ALSO
C     CHECK FOR NEGATIVE INTERNAL ENERGIES, IF
C     WE FIND SOME, SET THEM TO ZERO AFTER
C     SUBTRACTING THEM FROM ETH..
 2009 IF(AMX(K)/(TAU(I)*DY(J))-TOZONE)2010,2008,2008
 2010 WS=(U(K)**2+V(K)**2)/2.0
      Z(100)=Z(100)+AMX(K)
      WS=AMX(K)*(AIX(K)+WS)
      Z(101)=Z(101)+WS
      ETH=ETH-WS
      Z(102)=Z(102)+AMX(K)*U(K)
      Z(103)=Z(103)+AMX(K)*V(K)
      AMX(K)=0.0
      AIX(K)=0.0
      P(K)=0.0
      U(K)=0.0
      V(K)=0.0
      GO TO 2000
 2008 IF(AIX(K))2004,2000,2000
 2004 SUM=SUM+AIX(K)*AMX(K)
      AIX(K)=0.0
 2000 K=K+IMAX
 2001 CONTINUE
 2003 ETH=ETH-SUM
      Z(104)=Z(104)+SUM
 8000 IF(REZ)8001,8001,8002
 8002 IF(REZFCT)8004,8004,8003
 8004 REZ=0.
      GO TO 8001
 8003 CALL REZONE
 8001 RETURN
      END
```

```
$IBFTC ES       LIST,DECK,REF
      SUBROUTINE ES
C                                                                 ES  0900
C     METALLIC EQUATION OF STATE, SEE
C     GA-3216 REPORT.
C                                                                 ES  0980
   10 RHOW=AMX(K)/(TAU(I)*DY(J))                                  ES  0990
      ETA=RHOW/Z(115)                                             ES  1000
      VOW=1.0/ETA                                                 ES  1010
   11 P1=AIX(K)*RHOW*Z(116)                                       ES  1020
   12 P2=(Z(115)*TAU(I)*DY(J))**2*AIX(K)                          ES  1030
   13 P3=AMX(K)**2*Z(117)                                         ES  1040
   14 P4=Z(118)/(P2/P3+1.0)*AIX(K)*RHOW                           ES  1050
   15 P5=Z(119)*(ETA-1.0)                                         ES  1060
   16 IF(ETA-1.0)50,100,100                                       ES  1070
   50 IF(VOW-Z(120))55,55,75                                      ES  1080
   55 IF(AIX(K)-Z(122))100,100,75                                 ES  1090
   75 P7=Z(123)*(VOW-1.0)                                         ES  1100
      IF(P7-88.0)4002,4002,4003                                   ES  1110
 4003 P7=88.0                                                     ES  1120
 4002 CONTINUE                                                    ES  1130
      P8=EXP(P7)                                                  ES  1140
      P9=1.0/P8                                                   ES  1150
      P10=Z(124)*((VOW-1.0)**2)                                   ES  1160
      IF(P10-88.0)4000,4000,4001                                  ES  1170
 4001 P10=88.0                                                    ES  1180
 4000 CONTINUE                                                    ES  1190
      P11=EXP(P10)                                                ES  1200
      P12=1.0/P11                                                 ES  1210
      P(K)=P1+(P4+P5*P9)*P12                                      ES  1220
      GO TO 119
  100 P6=Z(126)*((ETA-1.0)**2)                                    ES  1230
      P(K)=P1+P4+P5+P6                                            ES  1240
  119 IF(P(K))999,999,200                                         ES  1250
  200 WSGX=.5                                                     ES  1260
      GO TO 500                                                   ES  1270
  999 P(K)=0.0                                                    ES  1280
      WSGX=.5+Z(125)                                              ES  1290
      GO TO 500                                                   ES  1300
  500 RETURN                                                      ES  1310
      END                                                         ES  1320
```

```
$IBFTC REZONE  LIST,DECK,REF
      SUBROUTINE REZONE                                                 REZ00010
C                                                                       REZ00980
C     CONSERVE MOMENTUM AND TOTAL ENERGY, INCREASE
C     ALL LINEAR DIMENSIONS BY 2. (THUS 4 CELLS
C     IN THE OLD GRID ARE COMBINED INTO 1 FOR
C     THE NEW GRID.)
      NIMAX=IMAX/2                                                      REZ00990
      NJMAX=JMAX/2                                                      REZ01000
      DO 10 J=1,NJMAX                                                   REZ01010
      K=(J-1)*NIMAX+2                                                   REZ01020
      L=(J-1)*2*IMAX+2                                                  REZ01030
      DO 11 I=1,NIMAX                                                   REZ01040
      M=L+IMAX                                                          REZ01050
   12 WSA=AMX(L)+AMX(M)+AMX(L+1)+AMX(M+1)                               REZ01060
      WSB=AMX(L)*(U(L)**2+V(L)**2)+AMX(M)*(U(M)                         REZ01070
     1**2+V(M)**2)+AMX(L+1)*(U(L+1)**2+V(L+1)**2)                       REZ01080
     2+AMX(M+1)*(U(M+1)**2+V(M+1)**2)                                   REZ01090
      U(K)=(U(L)*AMX(L)+U(M)*AMX(M)+U(L+1)*AMX(L+1)+                    REZ01100
     1U(M+1)*AMX(M+1))/WSA                                              REZ01110
      V(K)=(V(L)*AMX(L)+V(M)*AMX(M)+V(L+1)*AMX(L+1)+                    REZ01120
     1V(M+1)*AMX(M+1))/WSA                                              REZ01130
      AIX(K)=AIX(L)*AMX(L)+AIX(M)*AMX(M)+AIX(L+1)*                      REZ01140
     1AMX(L+1)+AMX(M+1)*AIX(M+1)                                        REZ01150
      AMX(K)=WSA                                                        REZ01160
      WS=U(K)**2+V(K)**2                                                REZ01170
      E=AIX(K)+WSB/2.0                                                  REZ01180
      AIX(K)=E/AMX(K)-.5*WS                                             REZ01190
      IF(K-2)14,14,13                                                   REZ01200
C     SET CELL QUANTITIES OF OLD GRID TO ZERO.
   13 AMX(L)=0.0                                                        REZ01210
      U(L)=0.0                                                          REZ01220
      V(L)=0.0                                                          REZ01230
      AIX(L)=0.0                                                        REZ01240
      P(L)=0.0                                                          REZ01250
      AMX(M)=0.0                                                        REZ01260
      U(M)=0.0                                                          REZ01270
      V(M)=0.0                                                          REZ01280
      AIX(M)=0.0                                                        REZ01290
      P(M)=0.0                                                          REZ01300
      AMX(L+1)=0.0                                                      REZ01310
      U(L+1)=0.0                                                        REZ01320
      V(L+1)=0.0                                                        REZ01330
      AIX(L+1)=0.0                                                      REZ01340
      P(L+1)=0.0                                                        REZ01350
      AMX(M+1)=0.0                                                      REZ01360
      U(M+1)=0.0                                                        REZ01370
      V(M+1)=0.0                                                        REZ01380
      AIX(M+1)=0.0                                                      REZ01390
      P(M+1)=0.0                                                        REZ01400
```

```
   14 K=K+1                                                    REZ014
      L=L+2                                                    REZ014
   11 CONTINUE                                                 REZ014
   10 CONTINUE                                                 REZ014
C     CALCULATE NEW DY AND Y (JMAX OF THEM).
   18 DO 999 J=1,JMAX                                          REZ014
      DY(J)=DY(J)*2.0                                          REZ014
  999 CONTINUE                                                 REZ014
      DO 99 J=1,JMAX                                           REZ014
      Y(J)=Y(J-1)+DY(J)                                        REZ014
   99 CONTINUE                                                 REZ015
   16 DX(1)=2.0*DX(1)                                          REZ015
      X(1)=DX(1)                                               REZ015
      WS=X(1)**2                                               REZ015
      IF(GAM)3001,3000,3001
 3001 WS=DX(1)
 3000 TAU(1)=PIDY*WS
C     CALCULATE NEW DX AND X, AND TAU(IMAX OF THEM)
   17 DO 98 I=2,IMAX                                           REZ015
      X(I)=X(I-1)+DX(1)                                        REZ015
      DX(I)=DX(1)                                              REZ015
      WSA=X(I)**2                                              REZ015
      IF(GAM)3002,3003,3002
 3002 TAU(I)=DX(I)
      GO TO 98
 3003 TAU(I)=PIDY*(WSA-WS)
      WS=WSA                                                   REZ016
   98 CONTINUE                                                 REZ016
      IMAX=NIMAX                                               REZ016
      JMAX=NJMAX                                               REZ016
C     PREPARE NOW TO SHUFFLE THE K ARRAYS SUCH
C     AS TO PRESERVE K=(J-1)*IMAX+I+1.
      DO 20 N=1,JMAX                                           REZ016
      J=JMAX+1-N                                               REZ016
      K=(J-1)*IMAX+1+IMAX                                      REZ016
      L=(J-1)*(IMAX+IMAX)+1+IMAX                               REZ016
      DO 21 I=1,IMAX                                           REZ016
 1000 AMX(L)=AMX(K)                                            REZ016
      AIX(L)=AIX(K)                                            REZ017
      U(L)=U(K)                                                REZ017
      V(L)=V(K)                                                REZ017
      P(L)=P(K)                                                REZ017
      IF(J-1)1002,1002,1001                                    REZ017
 1001 AMX(K)=0.0                                               REZ017
      AIX(K)=0.0                                               REZ017
      V(K)=0.0                                                 REZ017
      U(K)=0.0                                                 REZ017
      P(K)=0.0                                                 REZ017
 1002 K=K-1                                                    REZ018
      L=L-1                                                    REZ018
```

```
   21 CONTINUE                                                        REZO1820
   20 CONTINUE                                                        REZO1830
      IMAX=NIMAX*2                                                    REZO1840
      JMAX=NJMAX*2                                                    REZO1850
      II=NIMAX+1
      JJ=NJMAX+1
C     ADD ON NEW MASS WITH DENSITY=Z(111) IN TARGET
      DO 50 I=1,NIMAX
      K=(JJ-1)*IMAX+I+1
      DO 60 J=JJ,JMAX
      AMX(K)=Z(111)*TAU(I)*DY(J)
   60 K=K+IMAX
   50 CONTINUE
      JJ=(Z(147)/2.+.2)
      JJ=JJ+1
      DO 61 I=II,IMAX
      K=I+1+(JJ-1)*IMAX
      DO 62 J=JJ,JMAX
      AMX(K)=Z(111)*TAU(I)*DY(J)
   62 K=K+IMAX
   61 CONTINUE
C     RESET ACTIVE GRID MARKERS.
C     ASSUMPTION THAT ALL DX AND DY ARE =
C     NOTE, DVK=K(O)/(RHO(O)*DX SQ. )
      WS=DX(1)*DX(1)
      DVK=DDXN/(Z(111)*WS)
C
      JJ=JJ-1
      Z(147)=JJ
      I1=NIMAX+2                                                      REZO2040
      I2=NJMAX+2                                                      REZO2050
      WS=T+DTNA                                                       REZO2060
      NK=NC+1                                                         REZO2070
C     EDIT THE NEW GRID.
      WRITE (6,8004)WS,NK,DX(1)                                       REZO2080
      WRITE (6,8007)IMAX,(X(I),I=0,IMAX)                              REZO2090
      WRITE (6,8008)JMAX,(Y(J),J=0,JMAX)                              REZO2100
      WRITE (6,8009)IMAX,(DX(I),I=1,IMAX)                             REZO2110
      WRITE (6,8010)JMAX,(DY(J),J=1,JMAX)                             REZO2120
      WRITE (6,8011)IMAX,(TAU(I),I=1,IMAX)                            REZO2130
      KMAX=IMAX*JMAX+1                                                REZO2140
      IMAXA=IMAX+1                                                    REZO2150
      JMAXA=JMAX+1                                                    REZO2160
      KMAXA=KMAX+1                                                    REZO2170
      RETURN                                                          REZO2180
 8004 FORMAT(1H ////22H PROBLEM REZONED AT T=1PE12.6,6X,5HCYCLEI4,6X,3HDREZO2190
     1X=E12.6////)                                                    REZO2200
 8007 FORMAT(1H /10H X(I) I=0,I2/(5F16.6))                            REZO2210
 8008 FORMAT(1H /10H Y(J) J=0,I2/(5F16.6))                            REZO2220
 8009 FORMAT(1H /11H DX(I) I=1,I2/(5F16.6))                           REZO2230
```

```
 8010 FORMAT(1H /11H DY(J) J=1,I2/(5F16.6))                           REZ0224
 8011 FORMAT(1H /13H AREA(I) I=1,I2/(F16.6,4F18.6))
      END                                                             REZ0226
```

```
$IBFTC EDIT    LIST,DECK,REF
      SUBROUTINE EDIT                                                   EDIT0010
C                                                                       EDIT0990
C                                                                       EDIT1000
C     SENSE LITE (1) INDICATES LAST CYCLE OF THIS
C     RUN.
C     SENSE LITE (3) INDICATES FIRST CYCLE OF THIS
C     RUN.
  104 CALL SLITET(3,K000FX)                                             EDIT1040
       GO TO(106,108),K000FX                                            EDIT1050
  106 CALL SLITE (3)                                                    EDIT1060
      GO TO 126                                                         EDIT1070
  108 IF(CYCLE-CSTOP)110,122,122                                        EDIT1080
  110 IF(REZ)9901,112,124
  112 IF(AMOD(CYCLE,DUMPT7))114,124,114                                 EDIT1100
  114 IF(AMOD(CYCLE,PRINTL))120,126,120
  120 IF(AMOD(CYCLE,PRINTS))140,128,140                                 EDIT1150
C     NORMAL STOP ON THIS CYCLE.
  122 CALL SLITE (1)                                                    EDIT1160
C     DUMP ON TAPE 7.
  124 GO TO 1                                                           EDIT1170
  126 CALL SLITE (4)                                                    EDIT1180
  128 GO TO 6000                                                        EDIT1190
  130 GO TO 1000                                                        EDIT1200
  132 CALL SLITET(4,K000FX)                                             EDIT1210
       GO TO(134,136),K000FX                                            EDIT1220
  134 GO TO 5000                                                        EDIT1230
C     CHECK FOR ENERGY CHECK ERROR. WHERE
C     ECK= PERCENT ERROR/PER CYCLE.
C     ECK=(ETH-E)/ETH AT CYCLE N-(ETH-E)/ETH
C     AT CYCLE N-NPC ALL DIVIDED BY NPC, NOTE
C     NPC= NO. OF CYCLES BETWEEN ENERGY CHECK
  136 IF(ABS(ECK)-DMIN)140,140,9905                                     EDIT1240
  140 CALL SLITET(1,K000FX)                                             EDIT1250
       GO TO(142,144),K000FX                                            EDIT1260
  142 REWIND  7
      CALL SLITE (1)                                                    EDIT1280
  144 GO TO 10000                                                       EDIT1290
C                                                                       EDIT1300
C                                                                       EDIT1310
C                DUMP ON TAPE 7                                         EDIT1320
    1 IF(DUMPT7)30,3,3                                                  EDIT1330
    3 BACKSPACE  7
      WS=555.0                                                          EDIT1360
      WRITE ( 7)WS,CYCLE,N3
      WRITE ( 7)(Z(L),L=1,MZ)
    6 WRITE ( 7)(U(K),V(K),AMX(K),AIX(K),P(K),K=1,KMAXA)
    7 WRITE ( 7)X(0),(X(K),TAU(K),K=1,IMAX)
      WRITE ( 7)(Y(K),K=0,JMAX)
      WS=666.0                                                          EDIT1480
```

```
      WRITE ( 7)WS,WS,WS
      WRITE (6,8120)NC                                                  EDIT1500
   30 GO TO 126                                                         EDIT1510
C                                                                       EDIT1520
C                                                                       EDIT1530
 6000 NK=12                                                             EDIT1540
C     TABS ARE TANGENT ALPHAS.
      TAB(1)=0.02                                                       EDIT1550
      TAB(2)=0.04                                                       EDIT1560
      TAB(3)=0.06                                                       EDIT1570
      TAB(4)=0.08                                                       EDIT1580
      TAB(5)=0.10                                                       EDIT1590
      TAB(6)=0.15                                                       EDIT1600
      TAB(7)=0.20                                                       EDIT1610
      TAB(8)=0.25                                                       EDIT1620
      TAB(9)=0.30                                                       EDIT1630
      TAB(10)=0.4                                                       EDIT1640
      TAB(11)=0.5                                                       EDIT1650
      TAB(12)=1.0                                                       EDIT1660
 6010 DO 6012 I=1,18                                                    EDIT1670
 6012 PR(I)=0.0                                                         EDIT1680
      NK1=NK+2                                                          EDIT1690
      DO 6014 I=1,NK1                                                   EDIT1700
      AMK(I)=0.0                                                        EDIT1710
      PK(I)=0.0                                                         EDIT1720
 6014 QK(I)=0.0                                                         EDIT1730
      DO 6028 K=2,KMAX                                                  EDIT1740
 6017 PR(1)=0.0                                                         EDIT1760
      PR(2)=0.0                                                         EDIT1770
      PR(4)=0.
C     CALCULATE KINETIC ENERGY IN CELL K.
      WSB=(U(K)**2+V(K)**2)*.5
 6019 IF(AMX(K))9917,6028,6020                                          EDIT1790
 6020 I=NK1                                                             EDIT1800
      IF(V(K))6026,6026,6022                                            EDIT1810
 6022 WSA=ABS(U(K))/V(K)                                                EDIT1820
      DO 6024 I=1,NK                                                    EDIT1830
C     SEARCH FOR TAN ANGLE THAT VELOCITY VECTORS
C     MAKE.
      IF(TAB(I)-WSA)6024,6026,6026                                      EDIT1840
 6024 CONTINUE                                                          EDIT1850
      I=NK+1                                                            EDIT1860
 6026 WS=AMX(K)                                                         EDIT1870
C     SUM UP MASS BETWEEN ANGLES.
 6027 AMK(I)=AMK(I)+AMX(K)                                              EDIT1880
C     SUM UP RADIAL MOMENTA IN THE ANGLES.
      PK(I)=PK(I)+U(K)*AMX(K)                                           EDIT1890
C     SUM UP AXIAL MOMENTA IN THE ANG. . .
      QK(I)=QK(I)+V(K)*AMX(K)                                           EDIT1900
C     SUM UP TOTAL INTERNA' ENERGY
```

```
      PR(5)=PR(5)+AIX(K)*AMX(K)                                         EDIT1910
C     SUM UP TOTAL KINETIC ENERGY
      PR(6)=PR(6)+WSB*AMX(K)                                            EDIT1920
C     SUM UP TOTAL MASS
      PR(8)=PR(8)+AMX(K)                                                EDIT1930
 6028 CONTINUE                                                          EDIT1940
      PR(3)=PR(1)+PR(2)                                                 EDIT1950
      PR(7)=PR(5)+PR(6)                                                 EDIT1960
      XNRG=PR(7)                                                        EDIT1970
      PR(9)=PR(1)+PR(5)                                                 EDIT1980
      PR(10)=PR(2)+PR(6)                                                EDIT1990
      PR(11)=PR(3)+PR(7)                                                EDIT2000
      PR(12)=PR(4)+PR(8)                                                EDIT2010
      WSA=(ETH-PR(11))/ETH                                              EDIT2020
      IF(CYCLE)9931,9931,9932
 9931 NPC=1
 9932 PR(18)=(WSA-DNN)/FLOAT(NPC)
      ECK=PR(18)                                                        EDIT2040
      DNN=WSA                                                           EDIT2050
C     RESET CYCLE COUNTER BETWEEN ENERGY CHECK.
      NPC=0                                                             EDIT2060
      SUM=0.0                                                           EDIT2070
      DO 800 I=1,13                                                     EDIT2080
      SUM=SUM+QK(I)                                                     EDIT2090
  800 CONTINUE                                                          EDIT2100
C     RADET= TOTAL POSITIVE AXIAL MOMENTUM IN GRID
      RADET=SUM                                                         EDIT2110
  801 SUM=0.0                                                           EDIT2120
      DO 810 K=2,KMAX                                                   EDIT2130
      IF(AMX(K))810,810,802                                             EDIT2140
  802 IF(U(K))810,810,803                                               EDIT2150
  803 SUM=SUM+AMX(K)*U(K)                                               EDIT2160
  810 CONTINUE                                                          EDIT2170
C     RADER= TOTAL POSITIVE RADIAL MOMENTUM IN GRID.
      RADER=SUM                                                         EDIT2180
      SUM=0.0                                                           EDIT2190
      JJ=Z(147)                                                         EDIT2200
      DO 811 I=1,IMAX                                                   EDIT2210
      K=I+1                                                             EDIT2220
      DO 813 J=1,JJ                                                     EDIT2230
      IF(AMX(K))813,813,814                                             EDIT2240
  814 IF(U(K))813,813,816                                               EDIT2250
  816 SUM=SUM+U(K)*AMX(K)                                               EDIT2260
  813 K=K+IMAX                                                          EDIT2270
  811 CONTINUE                                                          EDIT2280
C     RADEB= TOTAL POSITIVE RADIAL MOMENTUM BELOW
C     INITIAL TARGET-PROJECTILE INTERFACE.
      RADEB=SUM                                                         EDIT2290
      PR(19)=0.0                                                        EDIT2300
      DO 6029 I=1,NK                                                    EDIT2310
```

```
 6029 PR(I+19)=PR(I+18)+AMK(I)
      PR(NK+20)=0.0
      PR(NK+21)=0.0
      WRITE (6,8116)PROB,NC,T,DTNA,TRAD,DTRAD,NR,N1,N2,N3,N4
      WRITE (6,8117)(PR(I),I=1,8)
      WRITE (6,8118)(PR(I),I=9,12
      WRITE (6,8119)RADEB,RADER,RADET,UVMAX,ETH,ECK
      WRITE (6,9040)N10,N11,I1,I2,I3,I4
      WRITE (6,8124)(I,AMK(I),PR(I+19),PK(I),QK(I),I=1,NK1)
 6090 GO TO 130
C**** END OF   S P  SUBROUTINE ****************************************
C
C
C**** SUBROUTINE PLOT *************************************************
 1000 GO TO 1030
 1030 WRITE (6,8116)PROB,NC,T,DTNA,TRAD,DTRAD,NR,N1,N2,N3,N4
      JMAX=JMAX
      WRITE (6,8307)X1,X2,XMAX,Y1,Y2,Y(JMAX)
      M=1
      IF(JMAX-52)1034,1036,1036
 1034 M=IABS(51-JMAX)/2
 1036 DO 1040 I=1,M
      WRITE (6,8308)
 1040 CONTINUE
 1044 J=I2
 1100 K=(J-1)*IMAX+1
 1105 DO 1180 I=1,I1
      K=K+1
C     REPLACE 600000000000 BY-17179869184
 1126 PR(I)=(-ABS(-17179869184))
 1150 IF(AMX(K))9917,1166,1160
C       X PARTICLE ONLY
C     REPLACE 6700000000    BY    922746880
 1160 PR(I)=OR(PR(I),  ABS(    922746880) )
      GO TO 1180
C     REPLACE 6000000000    BY    805306368
 1166 PR(I)=OR(PR(I),  ABS(    805306368) )
 1180 CONTINUE
 1200 IF(MOD(J,5))1210,1204,1210
 1204 IF(DY(J)-DY(J-1))1206,1208,1206
 1206 WRITE (6,8211)DY(J),J,(PR(I),I=1,I1)
      GO TO 1224
 1208 WRITE (6,8201)J,(PR(I),I=1,I1)
      GO TO 1224
 1210 IF(DY(J)-DY(J-1))1212,1214,1212
 1212 WRITE (6,8222)DY(J),(PR(I),I=1,I1)
      GO TO 1224
 1214 WRITE (6,8202)(PR(I),I=1,I1)
 1224 J=J-1
 1226 IF(J)1230,1230,1100
```

```
C      REPLACE 604000000000 BY-17716740096                               EDIT2820
 1230 PR(1)=(-ABS(-17716740096))                                          EDIT2830
      WRITE (6,8201)J,(PR(1),I=1,I1)                                      EDIT2840
      WRITE (6,8302)(I,I=0,IMAX,5)                                        EDIT2850
 1240 GO TO 132                                                           EDIT2860
C**** END OF  PLOT  SUBROUTINE ******************************************EDIT2870
C                                                                         EDIT2880
C                                                                         EDIT2890
C**** SUBROUTINE L P *****************************************************EDIT2900
 5000 WRITE (6,8116)PROB,NC,T,DTNA,TRAD,DTRAD,NR,N1,N2,N3,N4              EDIT2910
 5004 DO 5050 I=1,I1                                                      EDIT2920
      CALL SLITE (4)                                                      EDIT2930
      J=I2+1                                                              EDIT2940
      K=I2*IMAX+1+I                                                       EDIT2950
      DO 5046 L=1,I2                                                      EDIT2960
      J=J-1                                                               EDIT2970
      K=K-IMAX                                                            EDIT2980
 5012 IF(AMX(K))9917,5046,5014                                            EDIT2990
 5014 CALL SLITET(4,K000FX)                                               EDIT3000
       GO TO(5016,5019),K000FX                                            EDIT3010
 5016 WRITE (6,8135)I,X(I),DX(I)                                          EDIT3020
C     WS= DENSITY OF CELL(K) IN GRAMS/CM. CUBED.
 5019 WS=AMX(K)/(TAU(I)*DY(J))                                            EDIT3030
C     WSA= COMPRESSION = RHO/RHO NOT.
      WSA=WS/Z(111)                                                       EDIT3040
C     WSC=PRESSURE
      WSC=P(K)
C     FIRST COLUMN= (J) THE ROW NO.
C     SECOND COLUMN = RADIAL VELOCITY = U CM./SEC
C     OR  CM./SH.
C     THIRD COLUMN = AXIAL VELOCITY = V CM./SEC
C     OR  CM./SH.
C     FOURTH COLUMN = PRESSURE = F/A ERGS/(CM. CUBED)
C     OR  JERKS/(CM.CUBED)
C     FIFTH COLUMN = AMX = MASS IN GRAMS.
C     SIXTH COLUMN = RHO = DENSITY IN GRAMS/CC.
C     SEVENTH COLUMN=SPECIFIC INTERNAL ENERGY IN ERGS/GRAM
C     OR  JERKS/GRAM
C     EIGHT COLUMN = COMPRESSION = RHO/RHO NOT
C     NINTH COLUMN = Z VALUE (CM.) OF TOP OF CELL)
 50180WRITE (6,8108)J,U(K),V(K),WSC,AMX(K),                  WS,AIX(K),EDIT3060
     1WSA,Y(J)                                                            EDIT3070
 5046 CONTINUE                                                            EDIT3080
 5050 CONTINUE                                                            EDIT3090
      GO TO 136                                                           EDIT3100
C**** END OF   L P  SUBROUTINE ******************************************EDIT3110
C                                                                         EDIT3120
C                                                                         EDIT3130
C                ERROR                                                    EDIT3140
 9901 NK=110                                                              EDIT3150
```

```
      GO TO 9999
C                ENERGY CHECK
 9905 NK=136
      GO TO 9999
C                NEGATIVE MASS
 9917 NK=6015
      GO TO 9999
 9920 NK=904
      GO TO 9999
 9921 NK=912
      GO TO 9999
 9922 NK=918
      GO TO 9999
 9923 NK=922
      GO TO 9999
 9924 NK=926
 9999 NR=6
      CALL DUMP
10000 RETURN
C
C                FORMATS
 8108 FORMAT(I3,1X,1P2E14.6,3E15.6,E14.6,E15.6,E14.6)
 81160FORMAT(8H1PROBLEM6X,5HCYCLE9X,4HTIME13X,2HDT13X,4HTRAD11X,5HDTRAD1
     12X,2HNR6X,2HN14X,2HN24X,2HN34X,2HN4/(F7.1,I11,2X,1P4E16.7,I10,2X,4
     2I6))
 81170FORMAT(1H0//17X2HAI16X,2HAK14X,5HAI+AK15X,2HAM/4H DOT3X,1P4E18.7/3
     1H  X4X,4E18.7)
 81180FORMAT(12X,13H-------------5X,13H-------------5X,13H-------------5
     1X,13H-------------/7H TOTALS1P4E18.7)
 81190FORMAT(2H0 //16X,5HRADEB13X,5HRADER13X,5HRADET12X,7HMAX VEL13X,3HT
     1HE12X,9HREL ERROR/7X,1P6E18.7////)
 8120 FORMAT(1H0//21H TAPE 7 DUMP ON CYCLEI5////)
 81240FORMAT(3H  K12X,5HAM(K)11X,9HSUM AM(K)11X,4HP(K)13X,4HQ(K)/(I3,4X,
     11P4E18.7))
 8131 FORMAT(1H ///11H DY(J) J=1,I2//(10F12.3))
 8133 FORMAT(1H ///11H  Y(J) J=0,I2//(10F12.3))
 81350FORMAT(1H ///4H I =I3,6X,6HX(I) =F12.3,6X,7HDX(I) =F12.3//3H  J8X,
     11HX13X,1HY13X,3HF/A12X,3HAMX12X,3HRHO11X,3HAIX12X,4HCOMP11X,2H Y/)
 8201 FORMAT(I10,2H I54A2)
 8202 FORMAT(10X,2H I54A2)
 8211 FORMAT(F7.1,I3,2H I54A2)
 8222 FORMAT(F7.1,3X,2H I54A2)
 8302 FORMAT(I12,10I10)
 83070FORMAT(5H X1 =1PE12.6,3X,4HX2 =E12.6,3X,6HXMAX =E12.6,6X,4HY1 =E12
     1.6,3X,4HY2 =E12.6,3X,6HYMAX =E12.6)
 8308 FORMAT(1H /)
 9040 FORMAT(1H / 6I6)
      END
```

```
$IBFTC PH3      ..S  DECK,REF
      SUBROUTINE PH
C     NOTE, THIS CO.. IS CALLED RPM,
C     RIGID PLASTIC MATERIAL.
C     *** NOTE, BOUNDARY CONDITIONS ***
C     AT FREE SURFACE (GRID BOUNDARY) SET
C     THE STRESS AT THE RIGHT, TOP OR BOTTOM
C     = TO THE STRESS AT THE LEFT, BOTTOM OR
C     TOP RESPECTIVELY, INSURING THAT THE
C     ACCELERATION OF THE BORDER CELLS BE
C     ZERO.
C     FOR AXIS OF SYMMETRY, SET THE NORMAL
C     AND SHEAR STRESSES TO 0. SINCE REGARDLESS
C     OF MANNER OF COMPUTING THEM, THE AREA
C     OVER WHICH THEY ACT IS ZERO.
C     FOR REFLECTIVE BOUNDARIES AT THE BOTTOM
C     OR IN THE GRID, USING THE BOTTOM AS
C     A EXAMPLE, SET U(BOTTOM) = U(K) BUT
C     SNT=NORMAL STRESS AT THE TOP OF
C     A CELL. (THE ARRAY=ASN(I)).
C
C     STT=SHEAR STRESS AT THE TOP OF
C     A CELL. (THE ARRAY=AST(I)).
C
C     STR=SHEAR STRESS AT THE RIGHT OF
C     A CELL. (THE ARRAY=RST(I+1)).
C
C     SNR=NORMAL STRESS AT THE RIGHT OF
C     A CELL. (THE ARRAY=RSN(I+1)).
C
C     SNB=NORMAL STRESS AT THE BOTTOM OF
C     A CELL. (THE ARRAY=ASNB(I)).
C
C     STB=SHEAR STRESS AT THE BOTTOM OF
C     A CELL. (THE ARRAY=ASTB(I)).
C
C     SNL=NORMAL STRESS AT THE LEFT OF
C     A CELL. (THE ARRAY=RSN(I)).
C
C     STL=SHEAR STRESS AT THE LEFT OF
C     A CELL. (THE ARRAY=RST(I)).
C
C     DDVK=HOOP STRESS OF A CELL (ARRAY=SIG33(I)).
C
C     X1=UDOT OF A CELL, (ARRAY=DUDOT(I)
C
C     X2=VDOT OF A CELL, (ARRAY=DVDOT(I)
C     SIGC(I)=U(K BELOW)
C     GAMC(I)=V(K BELOW)
C     FEF IS A FLAG TO BYPASS THE STRENGTH
```

```
C       CALCULATIONS                                                    PH3 024
        VSAVE=VT
        IF(FEF)7778,7779,7778
C       NOTE, CLEAR THE PRESSURE ARRAY.
 7779   DO 9600 K=2,KMAX
        P(K)=0.
 9600   CONTINUE
        WS=I3
        DTT=DT
        DT=DT/WS
C       BIG=DV/DZ  CRIT
        BIG=DVK*DT*TABLM
C       PROVISIONS FOR SUBCYCLING THE STRENGTH
        DO 9000 NN=1,I3
C                                                                       PH3 023
C       NOTE, SET THE FLAGS FOR INCREASING THE
C       ACTIVE GRID COUNTERS TO 0.
        NRC=0
        NRT=0
        SUM=0.
C
      1 DO 3302 J=1,I2                                                  PH3 026
C                                                                       PH3 026
C       NOTE, SET UP DO LOOP IN J DIRECTION FIRST, NOTE                 PH3 027
C       THAT I2 IS THE LIMIT, NOT JMAX                                  PH3 027
C                                                                       PH3 028
      2 K=(J-1)*IMAX+2                                                  PH3 028
        N=K+IMAX                                                        PH3 029
C                                                                       PH3 029
C       NOTE, K IS THE INDEX OF CELL IN QUESTION, N                     PH3 030
C       IS THE INDEX OF CELL ABOVE.                                     PH3 030
C                                                                       PH3 031
C       ***, NOTE, THE STRESSES AT THE AXIS OF SYMMETRY                 PH3 031
C       ARE SET TO 0. SINCE REGARDLESS OF MANNER OF                     PH3 032
C       CALCULATION, THE AREA IS 0.                                     PH3 032
C                                                                       PH3 033
      3 SNL=0.                                                          PH3 033
        STL=0.                                                          PH3 034
C                                                                       PH3 034
C       SET UP DO LOOP IN THE I DIRECTION, NOTE THAT                    PH3 035
C       I1 IS THE LIMIT, NOT IMAX.                                      PH3 035
C                                                                       PH3 036
      4 DO 3361 I=1,I1                                                  PH3 036
C
C       AMDM= FACTOR FOR STRESS CUTOFF ON THE BASIS OF
C       THE DENSITY BEING LESS THAN  AMDM X THE INITIAL DENSITY
C
C       CHECK FOR RAREFIED MATERIAL IN CELL (K)
     40 IF(AMX(K)/(TAU(I)*DY(J))-AMDM*Z(115))3340,3340,38
     38 IF(J-1)720,720,721
```

```
  721 KBLO= K-IMAX
      IF(AMX(KBLO)/(TAU(I)*DY(J-1))-AMDM*Z(115))722,722,720
  722 DDVK=0.
      GO TO 3306
C                                                                       PH3 0375
  720 VT=0.
      II=I
      JN=J
C     ***************************************
C     CHECK FOR 1D PROBLEM
C     *************************************
      IF(IMAX-1)39,810,39
C     SET HOOP STRESS TO ZERO
  810 DDVK=0.
      GO TO 3306
C                                                                       PH3 0385
C     NOW WE WILL SET INDICES FOR A HOOP                                PH3 0390
C     STRESS CALC. OR A ECAL.                                           PH3 0395
C                                                                       PH3 0400
   39 IF(J-1)9908,41,47                                                 PH3 0405
C                                                                       PH3 0410
C     WE ARE IN THE BOTTOM ROW                                          PH3 0425
C                                                                       PH3 0430
   41 KA=N                                                              PH3 0435
      KB=K                                                              PH3 0440
      VV=1.
      UUU=1.                                                            PH3 0450
   42 IF(I-1)9907,43,44                                                 PH3 0455
C                                                                       PH3 0460
C     WE ARE IN THE LOWER LEFT CORNER                                   PH3 0465
   43 KL=K                                                              PH3 0470
      KR=K+1                                                            PH3 0475
      FD=1.
      E=1.                                                              PH3 0485
      GO TO 100                                                         PH3 0490
   44 IF(I-IMAX)46,45,9903                                              PH3 0495
C                                                                       PH3 0500
C     WE ARE IN THE LOWER RIGHT CORNER                                  PH3 0505
   45 KR=K                                                              PH3 0510
      KL=K-1                                                            PH3 0515
      E=1.
      FD=1.                                                             PH3 0525
      GO TO 100                                                         PH3 0530
C                                                                       PH3 0535
C     WE ARE IN BOTTOM ROW, BUT NOT AT                                  PH3 0540
C     AXIS OR RIGHT BOUNDARY OF GRID.                                   PH3 0545
C                                                                       PH3 0550
   46 KR=K+1                                                            PH3 0555
      KL=K-1                                                            PH3 0560
      E=1.                                                              PH3 0565
```

```
      FD=1.
      GO TO 100
C
C     NOT IN BOTTOM ROW
   47 IF(J-JMAX)54,48,9903
C
C     WE ARE IN THE TOP ROW
   48 KA=K
      KB=K-IMAX
      UUU=1.
      VV=1.
   49 IF(I-1)9907,50,51
C
C     WE ARE IN UPPER LEFT CORNER
   50 KR=K+1
      KL=K
      FD=1.
      E=1.
      GO TO 100
   51 IF(I-IMAX)53,52,9903
C
C     WE ARE IN UPPER RIGHT CORNER
   52 KR=K
      KL=K-1
      E=1.
      FD=1.
      GO TO 100
C
C     WE ARE AT THE TOP, BUT NOT AT
C     THE AXIS OR RIGHT BOUNDARY OF GRID
   53 KR=K+1
      KL=K-1
      E=1.
      FD=1.
      GO TO 100
C
C     WE ARE NOT AT THE TOP OR BOTTOM,
C     CHECK OUR POSITION WITH RESPECT TO THE
C     AXIS AND RIGHT BOUNDARY OF GRID.
   54 VV=1.
      KA=N
      KB=K-IMAX
      UUU=1.
   55 IF(I-1)9907,59,56
C
C     WE ARE ALONG THE AXIS
   59 KL=K
      KR=K+1
      E=1.
      FD=1.
```

```
      GO TO 100
   56 IF(I-IMAX)58,57,9903
C
C     WE ARE ALONG THE RIGHT BOUNDARY OF CRID
   57 KR=K
      KL=K-1
      E=1.
      FD=1.
      GO TO 100
C
C     WE ARE IN THE MESH, NOT AT ANY BOUNDARY
   58 E=1.
      FD=1.
      KR=K+1
      KL=K-1
      GO TO 100
  100 IF(VT)102,101,102
C     CALCULATE THE HOOP STRESS FOR CELL K.
  101 CALL HOOP
      GO TO 3306
C     CALCULATE THE CHANGE IN INTERNAL ENERGY
C     DUE TO THE WORK DONE BY THE STRESSES.
  102 CALL ECALC
      GO TO 801
C
C
C     CELL K IS VOID, SET ALL 9
C     STRESSES TO ZERO. ********************
C
 3340 SNT=0.
      STT=0.
      SNL=0.
      SNR=0.
      STL=0.
      STR=0.
      SNB=0.
      STB=0.
      DDVK=0.
      X1=0.
      X2=0.
      GO TO 3326
C
C     RETURN TO HERE AFTER CALCULATING THE
C     HOOP STRESS
 3306 IF(IMAX-I)9901,3311,3310
C     CHECK FOR RAREFIED MATERIAL  IN THE CELL TO THE
C     RIGHT.
 3310 IF(AMX(K+1))9902,3312,4000
 4000 IF(AMX(K+1)/(TAU(I+1)*DY(J))-AMDM*Z(115))3312,3312,14
C
```

```
C     WE ARE AT THE RIGHT BOUNDARY OF GRID
C     SET THE STRESSES ON THE RIGHT = TO
C     THOSE ON THE LEFT
 3311 SNR=SNL
      STR=STL
      GO TO 3316
C
C
C     THE CELL TO THE RIGHT OF CELL K IS VOID.
C     SET THE STRESSES ON THE RIGHT TO 0.
C
 3312 SNR=0.
      STR=0.
      DDVK=0.
      S1=0.
      S2=0.
      S3=0.
      S4=0.
      S5=0.
      GO TO 3316
C
C     WE ARE PREPARING TO CALCULATE THE STRESSES
C     AT THE RIGHT OF THIS CELL.
C     WE ARE NOT AT IMAX, BUT MAY BE AT J=1
C     OR J=JMAX OR IN THE MESH.
C
   14 KR=K+1
      II=I
      JN=J
      IF(J-1)9908,28,27
C
C     NOT IN BOTTOM ROW
   27 IF(J-JMAX)33,32,9903
C
C     WE ARE IN TOP ROW
   32 KA=K
      KAR=KR
      KB=K-IMAX
      KBR=KB+1
      UUU=1.
      VV=1.
      GO TO 31
C
C     WE ARE INSIDE THE MESH.
C     NOTE, THE SPECIAL BOUNDARY CONDITIONS
C     FOR EMPTY CELLS ADJACENT TO CELL K.
   33 KB=K-IMAX
  723 KBR=KB+1
  724 IF(AMX(KB))725,725,726
  725 KB=K
```

```
  726 IF(AMX(KBR))727,727,730
  727 KBR=K+1
  730 VV=1.
      KA=N                                                      PH3 1240
      KAR=KA+1                                                  PH3 1245
      GO TO 31                                                  PH3 1260
C                                                               PH3 1265
C     WE ARE IN THE BOTTOM ROW.                                 PH3 1270
   28 KB=K                                                      PH3 1275
      KBR=KR                                                    PH3 1280
      KA=N                                                      PH3 1285
      KAR=N+1                                                   PH3 1290
      UUU=1.
      VV=1.                                                     PH3 1300
   31 CALL GRADR                                                PH3 1305
C                                                               PH3 1310
C     CALCULATE THE VELOCITY GRADIENTS AT THE                   PH3 1315
C     RIGHT                                                     PH3 1320
   29 CALL STRESR                                               PH3 1325
C
C                                                               PH3 1330
C     CALCULATE THE NORMAL AND SHEAR STRESS                     PH3 1335
C     AT THE RIGHT.                                             PH3 1340
   30 CONTINUE                                                  PH3 1345
C                                                               PH3 1350
C     DONT PUT THE INDIVIDUAL STRESSES INTO                     PH3 1355
C     ARRAYS UNTIL LATER.                                       PH3 1360
      GO TO 3316                                                PH3 1365
C                                                               PH3 1370
 3316 IF(JMAX-J)9903,3315,3320                                  PH3 1375
C                                                               PH3 1380
C     WE ARE AT THE TOP OF THE GRID, SET THE                    PH3 1385
C     STRESSES AT THE TOP = THOSE AT BOTTOM OF                  PH3 1390
C     THE CELL.                                                 PH3 1395
C                                                               PH3 1400
C                                                               PH3 1405
 3315 SNT=ASN(I)                                                PH3 1410
      STT=AST(I)                                                PH3 1415
      DDVK=0.
      GO TO 3325                                                PH3 1420
C                                                               PH3 1425
C     WE ARE NOT AT THE TOP OF THE GRID.                        PH3 1430
C                                                               PH3 1440
C     CHECK FOR RAREFIED MATERIAL IN CELL ABOVE.
 3320 IF(AMX(N))9904,3322,4010
 4010 IF(AMX(N)/(TAU(I)*DY(J+1))-AMDM*Z(115))3322,3322,12
C                                                               PH3 1445
C     THE CELL ABOVE CELL (K) IS VOID                           PH3 1450
C     SET THE STRESSES ABOVE TO 0.                              PH3 1455
 3322 SNT=0.                                                    PH3 1460
```

```
      STT=0.                                                            PH3 146
      DDVK=0.
      S6=0.
      S7=0.
      S8=0.
      S9=0.
      S10=0.
      GO TO 3325                                                        PH3 147
C                                                                       PH3 147
C                                                                       PH3 148
C     WE WILL CALCULATE THE VELOCITY                                    PH3 148
C     GRADIENTS AND STRESSES AT THE TOP OF                              PH3 149
C     THE CELL.                                                         PH3 149
C                                                                       PH3 150
C     WE ARE NOT AT THE TOP(J=JMAX)                                     PH3 150
C                                                                       PH3 151
   12 KA=N                                                              PH3 151
      II=I
      JN=J
   21 IF(I-1)9907,15,16                                                 PH3 152
   16 IF(I-IMAX)18,17,9901                                              PH3 152
C                                                                       PH3 153
C     INSIDE THE MESH                                                   PH3 153
C     NOTE THE SPECIAL BOUNDARY CONDITIONS
C     FOR EMPTY CELLS ADJACENT TO CELL K.
   18 KAR=KA+1
      KR=K+1
  732 IF(AMX(KAR))733,733,734
  733 KAR=KA
  734 IF(AMX(KR))735,735,736
  735 KR=K
  736 UUU=1.
      VV=1.                                                             PH3 154
      KL=K-1                                                            PH3 156
      KAL=KA-1                                                          PH3 156
      GO TO 24                                                          PH3 157
C                                                                       PH3 157
C     ALONG THE RIGHT BOUNDARY                                          PH3 158
   17 KAR=KA                                                            PH3 158
      KR=K                                                              PH3 159
      KAL=KA-1                                                          PH3 159
      KL=K-1                                                            PH3 160
      UUU=1.                                                            PH3 160
      VV=1.
      GO TO 24                                                          PH3 161
C                                                                       PH3 162
C     WE ARE ALONG THE AXIS                                             PH3 162
   15 KL=K                                                              PH3 163
      KAL=KA                                                            PH3 163
C     *************************************************
```

```
C      CHECK FOR 1D PROBLEM
C      ************************************
       IF(IMAX-1)811,812,811
  812  KAR=KA
       KR=K
       UUU=1.
       GO TO 813
  811  KAR=KA+1
       KR=K+1
       UUU=1.
  813  VV=1.
C
C      CALCULATE THE VELOCITY GRADIENTS AT
C      THE TOP OF THE CELL.
   24  CALL GRADZ
C
C      CALCULATE THE STRESSES.
   25  CALL STRESZ
C
   26  CONTINUE
       GO TO 6999
C
C
C      ARRIVED HERE AFTER COMPLETION OF THE
C      CALCULATION OF THE STRESSES AT THE TOP.
 6999  IF(1-J)3325,7001,9908
C
C
C      WE ARE IN THE BOTTOM ROW, NOW
C      CHECK THE BOUNDARY CONDITION AT THE BOTTOM.
 7001  IF(CVIS)7003,7002,7002
C
C
C      BOTTOM BOUNDARY IS REFLECTIVE
 7002  SNB=0.
       STB=0.
       GO TO 3325
C
C
C      BOTTOM BOUNDARY IS TRANSMITTIVE, SET THE
C      BOTTOM STRESSES TO THE TOP (WE JUST
C      FINISHED CALCULATING THEM).
C
 7003  SNB=SNT
       STB=STT
       GO TO 3325
C
C      NOW, WE HAVE ALL THE STRESSES OF CELL K
C      THUS WE CAN CALCULATE U DOT AND VDOT.
 3325  CONTINUE
```

```
  300 CONTINUE                                                    PH3 18
      JN=J
      II=I
C                                                                 PH3 18
C     CALL DELTAU(COMPUTES UDOT)                                  PH3 18
      IF(J-1)310,310,311                                          PH3 18
  311 STB=AST(I)                                                  PH3 18
  310 CALL DELTAU                                                 PH3 18
C                                                                 PH3 18
  301 CONTINUE                                                    PH3 18
C     NOW CALL DELTAV(COMPUTES VDOT)                              PH3 18
  302 CONTINUE                                                    PH3 18
      IF(J-1)312,312,313                                          PH3 19
  313 SNB=ASN(I)                                                  PH3 19
  312 CALL DELTAV                                                 PH3 19
  303 CONTINUE                                                    PH3 19
C                                                                 PH3 19
C     BY NOW WE HAVE THE ACCELERATION                             PH3 19
C     (BOTH COMPONENTS) OF CELL K DUE TO                          PH3 19
C     THE STRESSES.                                               PH3 19
  304 IF(I-1)9907,3326,305                                        PH3 19
  305 IF(I-IMAX)306,3326,9901                                     PH3 19
C                                                                 PH3 19
C     ////////////////////////////////////////////////////////////
C     CHECK FOR OVERSHOOT IN THE RADIAL DIRECTION.                PH3 19
C     AT THE LEFT INTERFACE OF CELL(K),
C     ////////////////////////////////////////////////////////////
C     CALCULATE DELTA U AT CYCLE N/                               PH3 19
C     DELTA UDOT AT CYCLE N+1                                     PH3 19
  306 WS=-(U(K)-U(K-1))/(X1-DUDOT(I-1))                           PH3 19
  307 IF(WS)450,308,308                                           PH3 19
  308 IF(DT-WS)450,309,309                                        PH3 19
  450 UPR=0.                                                      PH3 19
      GO TO 400                                                   PH3 19
C                                                                 PH3 19
C     CHECK IF WS IS BETWEEN 0. AND DT                            PH3 20
C     IF LESS THAN ZERO, BYPASS CHECK.                            PH3 20
C     IF IT IS LESS THAN DT, REDUCE THE                           PH3 20
C     STRESS(NORMAL)BY THE RATIO WS/DT.                           PH3 20
  309 WS=WS/DT                                                    PH3 20
      SNL=SNL*WS                                                  PH3 20
      UPR=-1.                                                     PH3 20
C                                                                 PH3 20
C     CHECK THE OTHER COMPONENT.                                  PH3 20
  400 WS=-(V(K)-V(K-1))/(X2-DVDOT(I-1))                           PH3 20
C                                                                 PH3 20
C     NOW CHECK THE SIGN AND MAGNITUDE WITH                       PH3 20
C     RESPECT TO DT(HYDRO).                                       PH3 20
  401 IF(WS)501,408,408                                           PH3 20
C                                                                 PH3 20
```

```
C      IF(-1)BYPASS CHECK                                        PH3 2080
C      IF GREATER THAN 0. CHECK AGAINST DT                       PH3 2085
  408 IF(DT-WS)501,409,409                                       PH3 2090
C                                                                PH3 2095
C      IF(GREATER)BYPASS CHECK                                   PH3 2100
  501 UPZ=0.                                                     PH3 2105
      GO TO 500                                                  PH3 2110
  409 WS=WS/DT                                                   PH3 2115
C                                                                PH3 2120
C      REDUCE SHEAR STRESS AT THE RIGHT                          PH3 2125
C      BY WS/DT                                                  PH3 2130
      STL=STL*WS                                                 PH3 2135
      UPZ=-1.                                                    PH3 2140
C                                                                PH3 2145
C      IF P(K)=0. NO OVERSHOOT IN EITHER
C      COMPONENT.
C      IF P(K)=-1. THE SHEAR STRESS WAS
C      MODIFIED.
C      IF P(K)=1. THE NORMAL STRESS WAS
C      MODIFIED.
C      IF P(K)=2. BOTH OF THE STRESSES
C      REQUIRED MODIFICATIONS.
  500 CONTINUE
      IF(UPR)9601,9602,9602
 9601 IF(UPZ)9603,9604,9604
 9603 P(K-1)=2.
      GO TO 3326
 9602 IF(UPZ)9605,3326,3326
 9605 P(K-1)=-1.
      GO TO 3326
 9604 P(K-1)=1.0
      GO TO 3326
C      ****** NOTE; WE ONLY SET THE COMPLETE ARRAY FOR THE       PH3 2435
C      FIRST ROW ************                                    PH3 2440
 3326 IF(J-1)9902,3328,601                                       PH3 2445
 3328 ASN(I)=SNT                                                 PH3 2450
      AST(I)=STT                                                 PH3 2455
      RSN(I)=SNL                                                 PH3 2460
  640 RSN(I+1)=SNR                                               PH3 2465
      RST(I+1)=STR                                               PH3 2470
  641 ASNB(I)=SNB                                                PH3 2475
      RST(I)=STL                                                 PH3 2480
      ASTB(I)=STB                                                PH3 2485
      SIG33(I)=DDVK                                              PH3 2490
      DUDOT(I)=X1                                                PH3 2495
      DVDOT(I)=X2                                                PH3 2500
C
C      SET THE RIGHT STRESSES FROM CELL (K) TO
C      = THE LEFT STRESSES FOR CELL (K+1).
      SNL=SNR                                                    PH3 2505
```

```
      STL=STR                                                          PH3 25
      GO TO 3360
C                                                                      PH3 25
C     /////////////////////////////////////////////////
C     CHECK FOR OVERSHOOT DUE TO STRESSES                              PH3 25
C     AT THE TOP OF CELL(K-IMAX) OR
C     THE BOTTOM OF CELL(K).
C     //////////////////////////////////////////////////
C     *********                                                        PH3 25
C     CAME HERE AFTER CALCULATING A CELL IN A                          PH3 25
C     ROW DIFFERENT THAN FOR J=1  .                                    PH3 25
C     **********                                                       PH3 25
  601 KRM=K-IMAX                                                       PH3 25
      IF(AMX(KRM)/(TAU(I)*DY(J-1))-AMDM*Z(115))901,901,602
C     **********                                                       PH3 25
C     KRM=INDEX OF CELL BELOW                                          PH3 25
C     **********                                                       PH3 25
  602 WS=-(U(K)-U(KRM))/(X1-DUDOT(I))                                  PH3 25
C     **********                                                       PH3 25
C     REMEMBER, THE STRESSES,UDOT,VDOT, AND                            PH3 25
C     HOOP STRESS FOR CELL K HAVE NOT BEEN PLACED                      PH3 25
C     IN THE ARRAY.                                                    PH3 25
C     ***********                                                      PH3 26
  603 IF(WS)604,605,605                                                PH3 26
  605 IF(DT-WS)604,606,606                                             PH3 26
  604 UPR=0.                                                           PH3 26
      GO TO 607                                                        PH3 26
C     **********                                                       PH3 26
C     REDUCE THE SHEAR STRESS ON THE TOP                               PH3 26
C     **********                                                       PH3 26
  606 WS=WS/DT                                                         PH3 26
      AST(I)=AST(I)*WS                                                 PH3 26
      UPR=-1.                                                          PH3 26
C     CHECK OTHER COMPONENT                                            PH3 26
  607 WS=-(V(K)-V(KRM))/(X2-DVDOT(I))                                  PH3 26
  608 IF(WS)614,615,615                                                PH3 26
  615 IF(DT-WS)614,616,616                                             PH3 26
  614 UPZ=0.                                                           PH3 26
      GO TO 617                                                        PH3 26
C     ***********                                                      PH3 26
C     REDUCE THE NORMAL STRESS ON THE TOP                              PH3 26
C     **********                                                       PH3 26
  616 WS=WS/DT                                                         PH3 27
      ASN(I)=ASN(I)*WS                                                 PH3 27
      UPZ=-1.                                                          PH3 27
C     ***********                                                      PH3 27
C     SET INDICES FOR CELL BELOW FOR POSSIBLE UPDATING                 PH3 27
C     OF UDOT AND VDOT                                                 PH3 27
C     ***********                                                      PH3 27
  617 KK=K                                                             PH3 27
```

```
      KKK=N
      K=K-IMAX
      N=KK
      II=I
      JN=J-1
C     ***************
C     SAVE THE STRESSES OF CELL K
C     TEMPORARY.
C
      SNB=ASN(I)
      STB=AST(I)
      PK(1)=SNB
      PK(2)=STB
      PK(3)=STR
      PK(4)=SNR
      PK(5)=SNT
      PK(6)=STT
      PK(7)=SNL
      PK(8)=STL
      PK(9)=DDVK
      PK(10)=X1
      PK(11)=X2
C     NOW SET STRESSES FROM K-IMAX INTO
C     THE CORRECT STORAGE FOR THE
C     SUB-ROUTINES.
  626 SNB=ASNB(I)
      STB=ASTB(I)
      STR=RST(I+1)
      SNR=RSN(I+1)
      SNT=ASN(I)
      STT=AST(I)
      SNL=RSN(I)
      STL=RST(I)
      DDVK=SIG33(I)
      X1=DUDOT(I)
      X2=DVDOT(I)
  620 IF(UPZ)624,9700,9700
  624 CALL DELTAV
      GO TO 9702
 9700 IF(P(K)-1.)9710,9701,9710
 9710 IF(P(K))624,9701,624
 9701 CONTINUE
 9702 IF(UPR)9703,9704,9704
 9703 CALL DELTAU
      GO TO 9705
 9704 IF(P(K)-1.)9705,9703,9703
 9705 CONTINUE
  625 IF(J-2)800,650,651
  650 SIGC(I)=U(K)
      CAMC(I)=V(K)
```

```
      GO TO 800
  651 KBB=K-IMAX
      WSU=U(KBB)
      WSV=V(KBB)
      U(KBB)=SIGC(I)
      V(KBB)=GAMC(I)
C     SET FLAG TO 1.(USE THE LOOK-UP                                   PH3 2995
C     ROUTINE THAT THE HOOP STRESS USES)                               PH3 3000
  800 IF(I-2)802,803,803
C     SET THE VELOCITIES AT THE LEFT AND SAVE
C     THE OLD ONES.
  803 UTEF=U(K-1)
      VTEF=V(K-1)
      U(K-1)=SIGC(I-1)
      V(K-1)=GAMC(I-1)
  802 VT=1.
      GO TO 39                                                         PH3 3010
C     ** FINALLY GETTING AROUND TO CALCULATE                           PH3 3015
C     THE VELOCITIES AND INTERNAL ENERGIES.                            PH3 3020
C     CALCULATE THE RADIAL COMPONENT, AND AXIAL                        PH3 3025
  801 AIX(K)=AIX(K)+VISC
  670 CONTINUE
      IF(AIX(K)-VVABOV)700,700,656
  700 SUM=SUM+AIX(K)*AMX(K)
      AIX(K)=0.
  656 IF(I-2)652,805,805
C     RESET THE(N+1) VELOCITIES IN CELL (K-1)
  805 U(K-1)=UTEF
      V(K-1)=VTEF
      GO TO 652
  652 IF(J-3)653,654,654
  654 SIGC(I)=U(K)
      GAMC(I)=V(K)
      U(KBB)=WSU
      V(KBB)=WSV
      GO TO 653
C
C     ///////////////////////////////////////////////////////////////
C     NOTE, HERE WE CHECK ON THE
C     POSSIBLE OVERSHOOT FROM THE HOOP STRESS
  653 WSA=X1*DT
      WS=U(K)+WSA
      IF(U(K))661,658,657
  657 IF(WS)660,658,658
  658 U(K)=WS
      GO TO 659
  660 DX1=2.*PIDY/AMX(K)*DX(I)*DY(JN)
      DX1=-DX1*DDVK
      X1=X1-DX1
      DX1=DX1*ABS(U(K)/WSA)
```

```
      X1=X1+DX1
      U(K)=U(K)+X1*DT
      GO TO 659
  661 IF(WS)658,658,660
  659 V(K)=V(K)+X2*DT
      IF(ABS(U(K))-VVBLO)701,701,702
  701 SUM=SUM+U(K)**2/2.*AMX(K)
      U(K)=0.
  702 IF(ABS(V(K))-VVBLO)703,703,704
  703 SUM=SUM+V(K)**2/2.*AMX(K)
      V(K)=0.
  704 CONTINUE
C     VISC IS DI/DT
C     *** RESET THE INDICES NOW, K AND N
C     WERE TEMPORARY SET FOR CELL BELOW
  873 K=KK
      N=KKK
C     ************
C
C     WE NOW HAVE COMPLETED THE INTEGRATION OF
C     THE MOMENTUM AND ENERGY EQUATIONS
C     FOR CELL K-IMAX
C
C     ***********
C      WE CAN NOT PLACE ALL THE STRESSES OF CELL K
C     INTO THE (I)
C     ARRAY, SINCE THE OVERSHOOT(ON THE TOP)  OF CELL
C     K-IMAX+1 HAS NOT BEEN CHECKED
C
C     SET THE STRESSES THAT WE STORED
C     TEMPORARY IN PK(1) THRU PK(9),BACK INTO
C     THE STORAGE THAT THE SUBROUTINES
C     RECOGNIZE.
  900 SNB=PK(1)
      STB=PK(2)
      STR=PK(3)
      SNR=PK(4)
      SNT=PK(5)
      STT=PK(6)
      SNL=PK(7)
      STL=PK(8)
      DDVK=PK(9)
      X1=PK(10)
      X2=PK(11)
  901 ASNB(I)=ASN(I)
      ASTB(I)=AST(I)
      RSN(I)=SNL
      RST(I)=STL
      ASN(I)=SNT
      AST(I)=STT
```

```
C       UPDATE CELL K IF STRESS WAS CHANGED
        IF(UPZ)850,851,851
    850 CALL DELTAV
    851 IF(UPR)860,861,861
    860 CALL DELTAU
    861 CONTINUE
C       ***********                                                  PH3 3280
C       NOW SET THE UDOT AND VDOT AND                                PH3 3285
C       HOOP STRESS INTO THE PROPER ARRAY.                           PH3 3290
    902 DUDOT(I)=X1                                                  PH3 3295
        DVDOT(I)=X2                                                  PH3 3300
        SIG33(I)=DDVK                                                PH3 3305
    904 CONTINUE                                                     PH3 3330
        IF(I-2)999,998,998                                           PH3 3335
C       HERE, SET THE STRESS ON THE RIGHT INTO THE (I) ARRAY         PH3 3340
    998 RSN(I)=SNL                                                   PH3 3345
        RST(I)=STL                                                   PH3 3350
    999 CONTINUE                                                     PH3 3355
C       SET THE STRESS AT THE LEFT OF CELL (K+1) TO THE              PH3 3310
C       RIGHT OF CELL (K)                                            PH3 3315
    903 SNL=SNR                                                      PH3 3320
        STL=STR                                                      PH3 3325
        IF(I-IMAX) 3360,599,599
    599 RSN(I+1)=SNR
        RST(I+1) = STR
        GO TO 3360
C                                                                    PH3 3715
C       ***** END OF DO LOOP ON (I) ******                           PH3 3720
C                                                                    PH3 3725
   3360 K=K+1                                                        PH3 3730
        N=N+1                                                        PH3 3735
   3361 CONTINUE                                                     PH3 3740
C       CHECK HERE AT THE RIGHT OF ACTIVE
C       GRID.
        KLAST=K-1
        IF (ABS(U(KLAST))+ABS(V(KLAST))+AIX(KLAST)) 952,953,952
    952 NRC=1
    953 CONTINUE
C       ***** END OF DO LOOP IN THE (J) DIRECTION ************       PH3 3745
   3302 CONTINUE                                                     PH3 3750
C       HERE WE WILL UPDATE THE LAST
C       ROW.
C       SAVE THE OLD VELOCITIES
C       HERE WE NEED THE OLD VELOCITIES
        K=(I2-1)*IMAX+2
        JN=I2
        N=K-IMAX
    906 DO 980 I=1,I1
        IF(I-1)908,907,908
    907 KL=K
```

```
      GO TO 909
  908 KL=K-1
  909 IF(I2-JMAX)911,910,911
  910 KA=K
      GO TO 912
  911 KA=K+IMAX
  912 IF(I-IMAX)914,913,914
  913 KR=K
      GO TO 915
  914 KR=K+1
C     NOW WE HAVE THE INDICES FOR
C     SUBROUTINE ECALC.
  915 IF(I-1)917,916,917
  916 FLEFT(I)=U(K)
      YAMC(I)=V(K)
      WSU=U(N)
      WSV=V(N)
C     VELOCITIES(PHASE 1) FROM CELLS BELOW
C     ARE AVAILABLE FROM THE MAIN LOOP
C     AND ARE STORED IN THE ARRAYS(SIGC AND GAMC ).
      U(N)=SIGC(I)
      V(N)=GAMC(I)
      GO TO 919
  917 WSU=U(N)
      WSV=V(N)
      UTEF=U(K-1)
      VTEF=V(K-1)
C     SAVE THE UPDATED VELOCITIES
  918 U(N)=SIGC(I)
      V(N)=GAMC(I)
      U(K-1)=FLEFT(I-1)
      V(K-1)=YAMC(I-1)
  919 II=I
      KB=N
C     SET THE STRESSES FROM THE ARRAYS
C      INTO THE SINGLE STORAGE.
      SNT=ASN(I)
      STT=AST(I)
      STR=RST(I+1)
      SNR=RSN(I+1)
      SNB=ASNB(I)
      STB=ASTB(I)
      SNL=RSN(I)
      STL=RST(I)
      X1=DUDOT(I)
      X2=DVDOT(I)
      DDVK=SIG33(I)
      IF(JN-JMAX)930,940,930
C     IF WE ARE AT THE TOP BOUNDARY OF
C     THE GRID,SET THE STRESS GRADIENTS
```

```
C       TO ZERO
   940  SNT=SNB
        STT=STB
   930  IF(I-IMAX)943,941,943
C       IF WE ARE AT THE RIGHT BOUNDARY
C       OF THE GRID, SET THE STRSS GRADIENTS
C       TO ZERO
   941  STR=STL
        SNR=SNL
   943  CALL DELTAU
        CALL DELTAV
   920  CALL ECALC
   921  AIX(K)=AIX(K)+VISC
   991  CONTINUE
   994  CONTINUE
        IF(AIX(K)-VVABOV)705,705,922
   705  SUM=SUM+AIX(K)*AMX(K)
        AIX(K)=0.
   922  FLEFT(I)=U(K)
        YAMC(I)=V(K)
   923  U(K)=U(K)+DT*X1
        V(K)=V(K)+DT*X2
        IF(ABS(U(K))-VVBLO)706,706,707
   706  SUM=SUM+U(K)**2/2.*AMX(K)
        U(K)=0.
   707  IF(ABS(V(K))-VVBLO)708,708,709
   708  SUM=SUM+V(K)**2/2.*AMX(K)
        V(K)=0.
   709  CONTINUE
   951  IF(I-1) 925,926,925
   926  U(N)=WSU
        V(N)=WSV
        GO TO 924
C       RESET THE NEW VELOCITIES FOR THE LEFT
C       AND BOTTOM CELLS.
   925  U(N) = WSU
        V(N) = WSV
        U(K-1)=UTEF
        V(K-1)=VTEF
        GO TO 924
   924  K=K+1
        N=N+1
   980  CONTINUE
C       CHECK HERE AT THE TOP OF ACTIVE
C       MESH.
        K=K-1
        IF(ABS(U(K))+ABS(V(K))+AIX(K))950,954,950
   950  NRT=1
   954  CONTINUE
C       NOW INCREASE ACTIVE GRID COUNTERS IF
```

```
C       NEEDED.
        I1= I1+NRC
        I2= I2+NRT
        IF(I1-IMAX)6100,6100,6200
 6200   I1= IMAX
 6100   IF(I2-JMAX)6201,6201,6202
 6202   I2=JMAX
 6201   CONTINUE
        GO TO 7777
 9908   NK=39
        GO TO 9999
 9907   NK=42
        GO TO 9999
 9903   NK=44
        GO TO 9999
 9901   NK=3306
        GO TO 9999
 9902   NK=3310
        GO TO 9999
 9904   NK=3320
        GO TO 9999
 9900   NK=3305
        GO TO 9999
 9999   NR=123
        CALL DUMP
 7777   SUMX=0.
        DO 9001 I=1,I1
        K=I+1
        DO 9002 J=1,I2
        P(K)=0.
        IF(AIX(K))710,9002,9002
  710   SUMX=SUMX+AIX(K)*AMX(K)
        AIX(K)=0.
 9002   K=K+IMAX
 9001   CONTINUE
        ETH=ETH-SUM-SUMX
 9000   CONTINUE
        VT=VSAVE
        DT=DTT
 7778   RETURN
        END
```

```
$IBFTC GRADR   LIST,DECK,REF
      SUBROUTINE GRADR
C     CALCULATES THE VELOCITY GRADIENTS ON
C     THE RIGHT SIDE OF THE CELL
C     GRADR REQUIRES THE FOLLOWING INDICES.
C     I,J,K,KR,KA,KAR,KB,KBR.
C     S1=DU/DR***
      S1=(U(KR)-U(K))/DX(II)
      IF(ABS(S1)-Z(107))1,1,2
    1 S1=0.
    2 CONTINUE
C     S2=DV/DR***
      S2=(V(KR)-V(K))/DX(II)
      IF(ABS(S2)-Z(107))3,3,4
    3 S2=0.
    4 CONTINUE
      WS=2.*DY(JN)
C     S3=DU/DZ***
      S3=((U(KA)+U(KAR))/2.-(U(KB)+U(KBR))/2.)/WS
      IF(ABS(S3)-Z(107))5,5,6
    5 S3=0.
    6 CONTINUE
C     S4=DV/DZ***
      S4=((V(KA)+V(KAR))/2.*VV-(V(KB)+V(KBR))/2.*UUU)/WS
      IF(ABS(S4)-Z(107))7,7,8
    7 S4=0.
    8 CONTINUE
C     S5=U/R***
      IF(GAM)9,12,9
   12 S5=(U(KR)+U(K))/(2.*X(II))
      IF(ABS(S5)-Z(107))9,9,10
    9 S5=0.
   10 CONTINUE
      RETURN
      END
```

```
$IBFTC GRADZ   LIST,DECK,REF
      SUBROUTINE GRADZ
C     CALCULATES THE VELOCITY GRADIENTS AT THE
C     TOP OF THE CELL
C     S6=DU/DZ***
      S6=(U(KA)-U(K))/DY(JN)
      IF(ABS(S6)-Z(107))1,1,2
    1 S6=0.
```

```
    2 CONTINUE
C     S7=DV/DZ***
      S7=(V(KA)-V(K))/DY(JN)
      IF(ABS(S7)-Z(107))3,3,4
    3 S7=0.
    4 CONTINUE
      WS=2.*DX(II)
C     S8=DU/DR***
      S8=((U(KAR)+U(KR))/2.*VV-(U(KAL)+U(KL))/2.*UUU)/WS
      IF(ABS(S8)-Z(107))5,5,6
    5 S8=0.
    6 CONTINUE
C     S9=DV/DR   ************
      S9=((V(KAR)+V(KR))/2.-(V(KAL)+V(KL))/2.)/WS
      IF(ABS(S9)-Z(107))7,7,8
    7 S9=0.
    8 CONTINUE
C     S10=U/R***
      IF(GAM)9,12,9
   12 S10=(U(KA)+U(K))/(X(II)+X(II-1))
      IF(ABS(S10)-Z(107))9,9,10
    9 S10=0.
   10 CONTINUE
      RETURN
      END
```

```
$IBFTC STRESR  LIST,DECK,REF
      SUBROUTINE STRESR
C     THIS ROUTINE CALCULATES THE NORMAL
C     AND SHEAR STRESS AT THE RIGHT
C     HAND BOUNDARY OF THE CELL
C     CALCULATE SNR(SIGMA 11 AT THE RIGHT)
C     NOTE, WE CAN HAVE VISCOSITY OR STRENGTH OR BOTH
C
      NEWT=0
      IF(DKE)1,1,91
   91 IF(DDXN)93,93,1
   93 NEWT=1
      B=0.
      GO TO 100
    1 WS=.66666*(S1*S1+S4*S4+S5*S5)+.5*
     1(S3+S2)**2
C     THAT WAS THE STRESS DEVIATOR=
C     EPSILON DOT (AB) * EPSILON DOT (AB)
C     K IS STORED IN DDXN
      WSA=WS*DX(II)*DX(II)
      IF(SQRT(WSA)-Z(112)*DXN)3,3,4
    3 B=0.
      GO TO 100
    4 CONTINUE
      WSA=BIG
C     NOTE, BIG IS CALCULATED IN PH3
      IF(ABS(S1)-WSA)10,10,11
   11 BUGR=DDXN
      GO TO 12
   10 BUGR=DDXN*ABS(S1)/WSA
   12 B=SQRT(2.*BUGR*BUGR/WS)
  100 EDOT11=S1
C     NOTE, S1=DU/DR
C     S1=DU/DR, S4=DV/DZ, S5=U/R
      EDOTAA=S1+S4+S5
      EPD11=EDOT11-EDOTAA/3.
C     NOW CALCULATE THE NORMAL STRESS
      SNR=(B+DKE)*EPD11
C     NOW THE SHEAR STRESS
C     DELTA 12 IS ZERO, THUS
C     EPD12=EDOT12
      EDOT12=(S3+S2)/2.
C     S3=DU/DZ, S2=DV/DR
      IF(NEWT)95,95,96
   96 B=0.
      GO TO 97
   95 IF(ABS(S4)-WSA)13,13,14
   14 BUGZ=DDXN
      GO TO 15
   13 BUGZ=DDXN*ABS(S4)/WSA
```

```
   15 B=SQRT(2.*BUGZ*BUGZ/WS)
   97 STR=(B+DKE)*EDOT12
      RETURN
      END
```

```
$IBFTC STRESZ  LIST,DECK,REF
      SUBROUTINE STRESZ
C     THIS ROUTINE CALCULATES THE NORMAL AND SHEAR
C     STRESS AT THE TOP OF THE CELL.
C     CALCULATE SNT(SIGMA 22 AT THE TOP)
C
C     NOTE, WE CAN HAVE VISCOSITY OR STRENGTH OR BOTH
      NEWT=0
      IF(DKE)1,1,91
   91 IF(DDXN)93,93,1
   93 NEWT=1
      B=0.
      GO TO 100
    1 WS=.66666*(S8*S8+S7*S7+S10*S10)+.5*
     1(S6+S9)**2
      WSA=WS*DY(JN)*DY(JN)
      IF(SQRT(WSA)-Z(112)*DXN)3,3,4
    3 B=0.
      GO TO 100
    4 CONTINUE
C      NOTE ,S7=DV/DZ
      WSA=BIG
      IF(ABS(S7)-WSA)6,6,7
    7 BUGR=DDXN
      GO TO 8
    6 BUGR=DDXN*ABS(S7)/WSA
    8 CONTINUE
      B=SQRT(2.*BUGR*BUGR/WS)
C     NOW SIGMA 22 = B*EPD22
  100 EPD22=S7-(S8+S7+S10)/3.
      SNT=(B+DKE)*EPD22
      EPD21=(S6+S9)/2.
C     NOTE, S8=DV/DR
      IF(NEWT)95,95,96
   96 B=0.
      GO TO 97
   95 IF(ABS(S8)-WSA)10,10,11
   11 BUGZ=DDXN
```

```
   GO TO 12
10 BUGZ=DDXN*ABS(S8)/WSA
12 B=SQRT(2.*BUGZ*BUGZ/WS)
97 STT=(B+DKE)*EPD21
   RETURN
   END
```

```
$IBFTC HOOP    LIST,DECK,REF
      SUBROUTINE HOOP
C     HERE WE WILL CALCULATE THE HOOP
C     STRESS FOR CELL K.
C     K IS IN (DDXN)
C     ETA ZERO(VISCOSITY)IS IN DKE
C     THE HOOP STRESS IS STORED IN DDVK
C     GAM IS A FLAG FOR THE TYPE OF
C     COORDINATE SYSTEM.
      IF(GAM)101,102,101
  101 DDVK=0.
      GO TO 103
  102 WS=X(II)+X(II-1)
      EDOT33=U(K)/WS*2.
      IF(DDXN)1,1,2
C     WE ASSUME WE HAVE A VISCOUS MATERIAL.
    1 B=DKE
      GO TO 100
C     CALCULATE B,WE HAVE A RIGID PLASTIC MATERIAL
    2 WSR=DX(II)
      WSZ=DY(JN)
      WSA=((U(KR)*E-U(KL)*FD)/(2.*WSR))**2
      IF(ABS(WSA)-Z(107))10,10,11
   10 WSA=0.
   11 CONTINUE
      WSB=((V(KA)*UUU-VV*V(KB))/(2.*WSZ))**2
      IF(ABS(WSB)-Z(107))12,12,13
   12 WSB=0.
   13 CONTINUE
      WSC=(2.*U(K)/WS)**2
      WSD=(U(KA)-U(KB))/(2.*WSZ)
      WSD=((V(KR)-V(KL))/(2.*WSR)+WSD)**2
      IF(ABS(WSD)-Z(107))14,14,15
   14 WSD=0.
   15 CONTINUE
      B=.66666*(WSA+WSB+WSC)+.5*WSD
      WSA=(DX(II)+DY(JN))/2.
      WSA=B*WSA*WSA
      IF(SQRT(WSA)-Z(112)*DXN)3,3,4
    3 B=0.
      GO TO 100
    4 CONTINUE
      B=SQRT(2.*DDXN*DDXN/B)
C     NOW SIGMA 33=B*EDOT OF 33
  100 DDVK=B*EDOT33
  103 RETURN
      END
```

```
$IBFTC DELTAU  LIST,DECK,REF
      SUBROUTINE DELTAU
C     THIS SUBROUTINE COMPUTES THE ACCELERATION
C     OF THE CELL DUE TO THE STRESSES
C     IN THE RADIAL DIRECTION.
C     ACTING ON THIS CELL (5 OF THEM).
C     STORE THE RADIAL COMPONENT OF THE
C     ACCELERATION IN X1.
      WS=TAU(II)/PIDY
      IF(GAM)1,2,1
    1 WSD=1.
      WSE=1.
      GO TO 3
    2 WSD=X(II)
      WSE=X(II-1)
    3 WSA=DY(JN)*(SNR*WSD-SNL*WSE)
      IF(GAM)6,7,6
    6 WSF=1.
      GO TO 4
    7 WSF=2.
    4 WSB=WS/WSF*(STT-STB)
      WSC=DX(II)*DY(JN)*DDVK
      X1=PIDY/AMX(K)*WSF*(WSA+WSB-WSC)
      RETURN
      END
```

```
$IBFTC DELTAV  LIST,DECK,REF
      SUBROUTINE DELTAV
C     AXIAL COMPONENT
C     THIS SUBROUTINE COMPUTES THE ACCELERATION OF
C     THE CELL DUE TO THE STRESSES ACTING
C     ON THIS CELL (4 OF THEM). STORE THE
C     AXIAL COMPONENT IN X2.
      IF(GAM)1,2,1
    1 WSB=1.
      WSD=1.
      WSF=1.
      GO TO 3
    2 WSB=2.
      WSD=X(II)
      WSF=X(II-1)
    3 WS=(SNT-SNB)/WSB*TAU(II)/PIDY
      WSA=DY(JN)*(STR*WSD-STL*WSF)
      X2=PIDY/AMX(K)*WSB*(WS+WSA)
```

```
      RETURN
      END




$IBFTC ECALC    LIST,DECK,REF
      SUBROUTINE ECALC
C     THIS ROUTINE WILL CALCULATE THE CHANGE
C     IN SPECIFIC INTERNAL ENERGY DUE TO THE
C     WORK DONE BY THESE STRESSES.
C     STORE IT IN (VISC).
      WSD=TAU(II)*((U(K)+U(KA))/2.*STT+
     1(V(K)+V(KA))/2.*SNT)
      WSE=TAU(II)*((U(K)+U(KB))/2.*STB+
     1(V(K)+V(KB))/2.*SNB)
      IF(GAM)1,2,1
    1 WSF=1.
      WSG=1.
      WSH=1.
      GO TO 3
    2 WSF=2.
      WSG=X(I)
      WSH=X(II-1)
    3 WS=WSF*PIDY*DY(JN)
      WSA=WS*WSG*((U(KR)+U(K))/2.*SNR+
     1(V(KR)+V(K))/2.*STR)
      WSB=WS*WSH*((U(K)+U(KL))/2.*SNL+
     1(V(K)+V(KL))/2.*STL)
      WSA=(WSA-WSB+WSD-WSE)/AMX(K)*DT
      WSE=X1*DT
      WSD=X2*DT
      WSB=WSE*(U(K)+WSE/2.)+WSD*(V(K)+WSD/2.)
      VISC=WSA-WSB
      RETURN
      END
```

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1. ORIGINATING ACTIVITY (Corporate author) General Atomic Division General Dynamics Corporation San Diego, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

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10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Ballistic Research Laboratories Aberdeen Proving Ground, Maryland

13. ABSTRACT

The three principal areas of activity,

1. Numerical solutions of problems in impact,
2. Code development for solving impact problems, and
3. Analytical work on the theory of the impact process,

are reviewed, utilizing wherever possible cited papers which have been published during this past year as part of the project work. The investigations covered in these papers are described only briefly in the present status report, familiarity with or availability of the original documents being assumed.

The major part of the present discussion is devoted to a status report of unfinished work on the problem of computing strength-dependent and viscous impact flows. A computer program is described for generalizing Eulerian hydrodynamic codes to include these effects and sample calculations are given.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Hypervelocity impact						
Hydrodynamics of impact						
Numerical solutions of impacts						

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